Getting to plot in **R**

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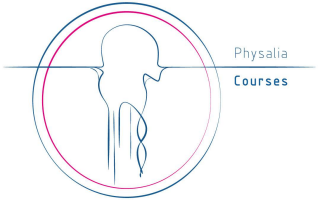
IN THE FORSCHUNGSVERBUND BERLIN E.V.



Plotting in **R**

1. Introduction
2. Plotting with traditional graphics
3. Plotting with `ggplot`
4. Conclusion: traditional graphics vs. `ggplot`

Why plot in **R**?

- Powerful (large range of plot types)
- Fully customizable (make your own style)
- Practical (integrate your plots and your code together)

Graphics paradigms in **R**

They are three dominant graphics paradigms in **R**:

- traditional graphics (based on `graphics`)
- `lattice` (based on `grid`)
- `ggplot2` (based on `grid`)

Graphics paradigms in **R**

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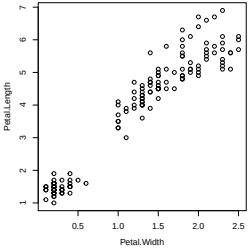
- `ggplot2` (based on `grid`)

Note:

- `graphics` and `grid` are part of any basic installation of **R**
- `lattice` is part of the so-called list of CRAN recommended packages
- `ggplot2` is part of the `tidyverse` universe (from RStudio)
- we will focus on traditional graphics and `ggplot2` (`lattice` is excellent but a bit more difficult)
- some other packages are sometimes useful too (e.g. `rgl`, `plotly`)

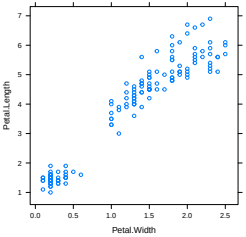
An example (using default settings)

```
plot(Petal.Length ~ Petal.Width, data = iris)
```



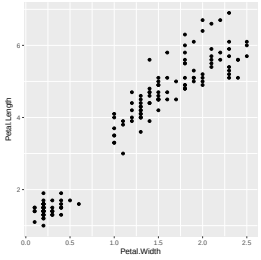

```
library(lattice)

xyplot(Petal.Length ~ Petal.Width, data = iris)
```




```
library(ggplot2)

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



How to learn on your own?

1. Check the examples readily available in **R**, e.g.

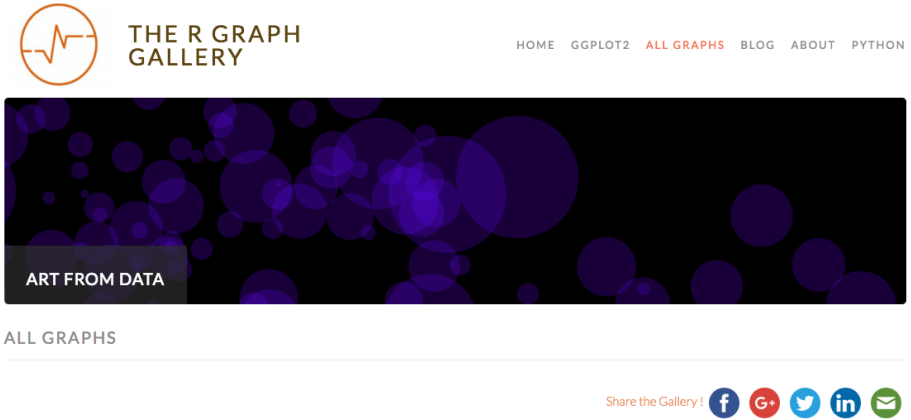
```
demo(graphics)
demo(image)
demo(persp)
demo(colors)
demo(plotmath)
demo(Hershey)

example(plot)
example(boxplot)
example(hist)
example(bartplot)

browseVignettes(package = "ggplot2")
```

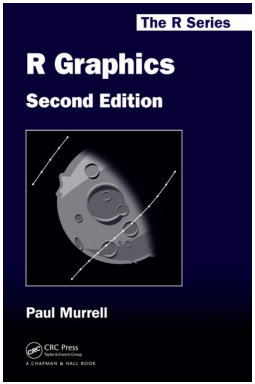
How to learn on your own?

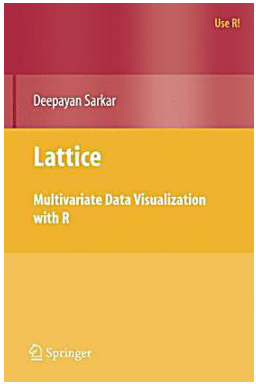
2. Scroll the web:
(e.g. `http://www.r-graph-gallery.com/all-graphs/`)

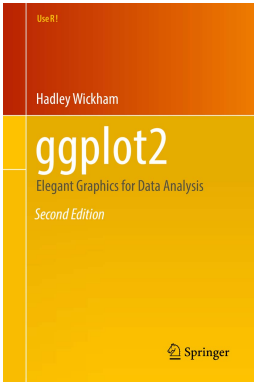


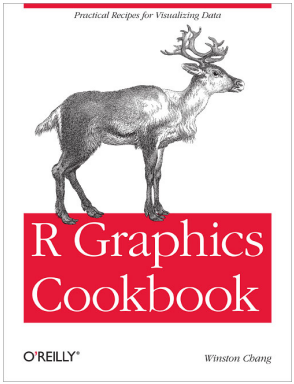
How to learn on your own?

3. Read books:









Plotting in **R**

1 Introduction

2 Plotting with traditional graphics

3 Plotting with ggplot

4 Conclusion: traditional graphics vs. ggplot

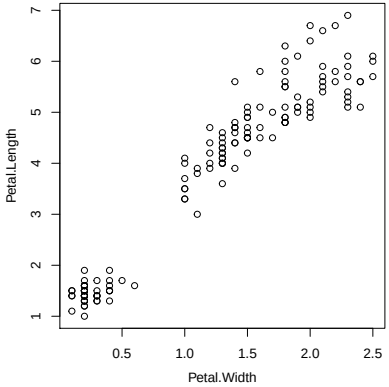
Plotting in **R**

1. Introduction
2. Plotting with traditional graphics
   - scatter plot
   - box plots
   - histograms
   - bar plots
   - aesthetics
   - saving your plot
   - other plots
3. Plotting with `ggplot`
   - introduction
   - scatter plots
   - box plots
   - histograms
   - bar plots
   - aesthetics
   - saving your plot
   - other plots
4. Conclusion: traditional graphics vs. `ggplot`

Traditional graphics: scatter plots

In traditional graphics, use `plot()` to draw a scatter plot:

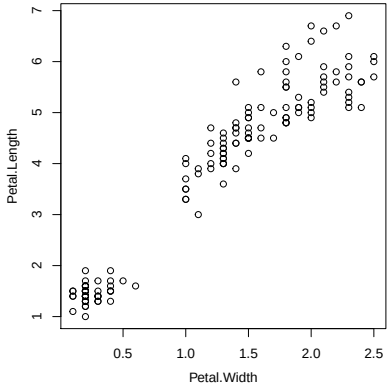
```
plot(Petal.Length ~ Petal.Width, data = iris)
```



Traditional graphics: scatter plots

You can choose what type of scatter plot to display with argument type:

```
plot(Petal.Length ~ Petal.Width, data = iris, type = "p")
```

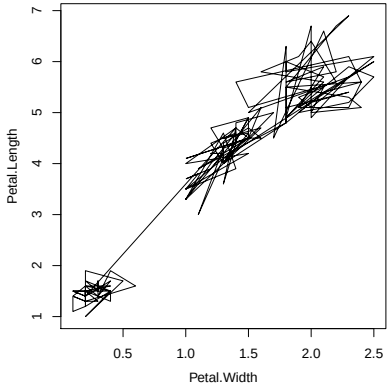


Note: see `"?plot.default"`.

Traditional graphics: scatter plots

You can choose what type of scatter plot to display with argument type:

```
plot(Petal.Length ~ Petal.Width, data = iris, type = "l")
```

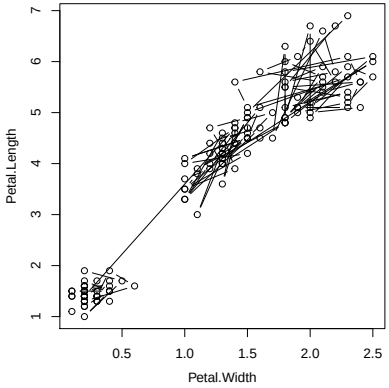


Note: it makes more sense when data are ordered...

Traditional graphics: scatter plots

You can choose what type of scatter plot to display with argument type:

```
plot(Petal.Length ~ Petal.Width, data = iris, type = "b")
```

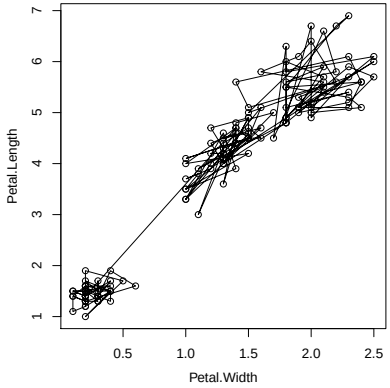


Note: it makes more sense when data are ordered...

Traditional graphics: scatter plots

You can choose what type of scatter plot to display with argument type:

```
plot(Petal.Length ~ Petal.Width, data = iris, type = "o")
```

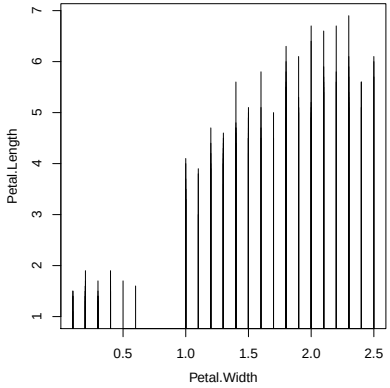


Note: it makes more sense when data are ordered...

Traditional graphics: scatter plots

You can choose what type of scatter plot to display with argument type:

```
plot(Petal.Length ~ Petal.Width, data = iris, type = "h")
```

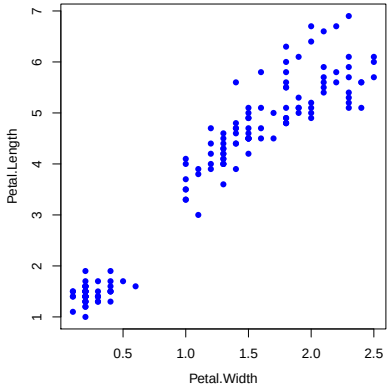


Note: it makes more sense when x-values are unique...

Traditional graphics: scatter plots

You can change point shapes (pch) and colour (col):

```
plot(Petal.Length ~ Petal.Width, data = iris, pch = 16, col = "blue")
```

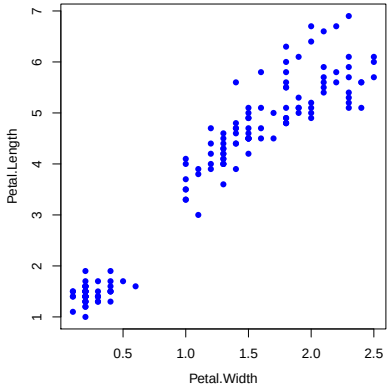


Note: you can use colour names.

Traditional graphics: scatter plots

You can change point shapes (pch) and colour (col):

```
plot(Petal.Length ~ Petal.Width, data = iris, pch = 16, col = 4)
```

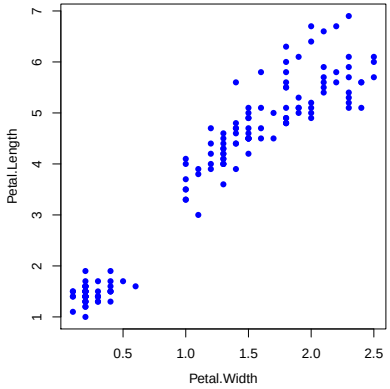


Note: you can use numbers to describe basic colours.

Traditional graphics: scatter plots

You can change point shapes (pch) and colour (col):

```
plot(Petal.Length ~ Petal.Width, data = iris, pch = 16, col = "#0000FFFF")
```



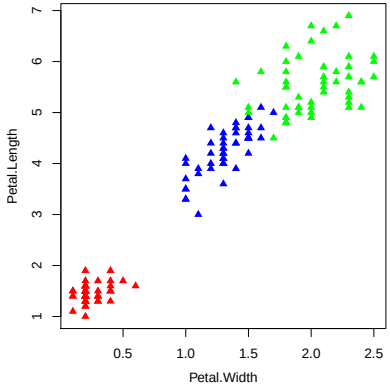

```
rgb(red = 0, green = 0, blue = 255, alpha = 255, maxColorValue = 255)
## [1] "#0000FFFF"
```

Note: you can have full control using hexadecimal!!

Traditional graphics: scatter plots

You can change point shapes (pch) and colour (col):

```
palette(c("red", "blue", "green"))
plot(Petal.Length ~ Petal.Width, data = iris, pch = 17, col = iris$Species)
```

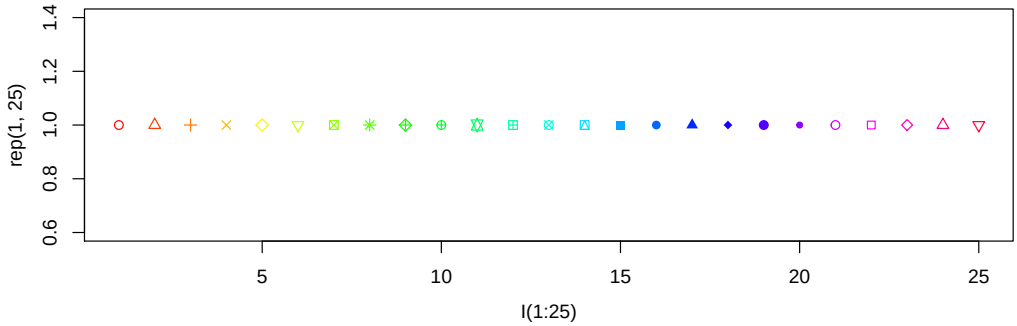


Note: you can use a palette to match the levels of a factor.

Traditional graphics: scatter plots

You can change point shapes (pch) and colour (col):

```
plot(rep(1, 25) ~ I(1:25), data = iris, pch = 1:25, col = rainbow(25))
```



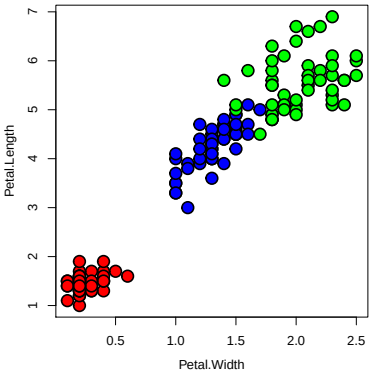
Note:

- there are 25 basic symbols (but other ways allow to use many more)
- check `"?rainbow"` for a list of different color palettes
- the `I()` allows for the creation of the vector before being interpreted by `plot()`

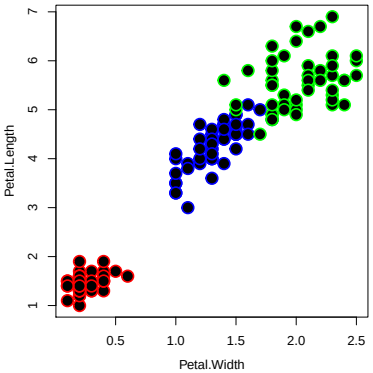
Traditional graphics: scatter plots

For some point shapes you can set both an outline colour (col) and background colour (bg):

```
palette(c("red", "blue", "green"))
plot(Petal.Length ~ Petal.Width, data = iris, cex = 2,
     pch = 21, col = "black", bg = iris$Species, lwd = 2)
```



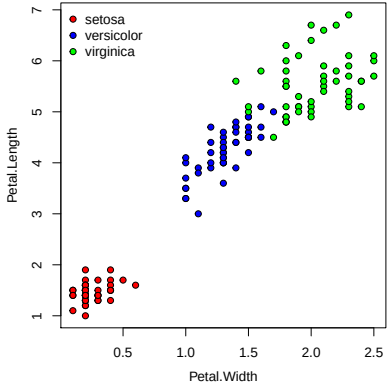

```
palette(c("red", "blue", "green"))
plot(Petal.Length ~ Petal.Width, data = iris, cex = 2,
     pch = 21, col = iris$Species, bg = "black", lwd = 2)
```



Traditional graphics: scatter plots

You can add a legend to the plot:

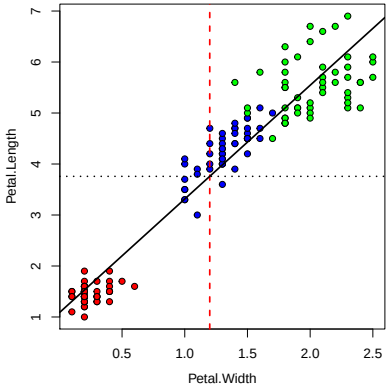
```
palette(c("red", "blue", "green"))
plot(Petal.Length ~ Petal.Width, data = iris, pch = 21, bg = iris$Species)
legend(x = "topleft", legend = c("setosa", "versicolor", "virginica"), pch = 21, pt.bg = c("red", "blue", "green"), bty = "n")
```



Traditional graphics: scatter plots

You can add lines to the plot:

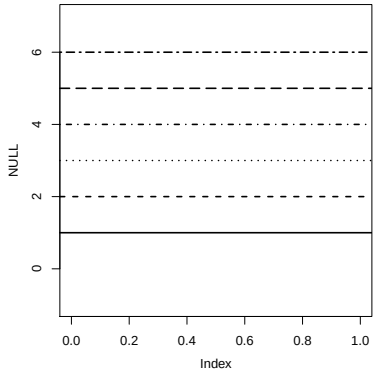
```
palette(c("red", "blue", "green"))
plot(Petal.Length ~ Petal.Width, data = iris, pch = 21, bg = iris$Species)
abline(v = mean(iris$Petal.Width), lty = 2, col = "red", lwd = 2)
abline(h = mean(iris$Petal.Length), lty = 3, col = "black", lwd = 2)
abline(a = 1.084, b = 2.23, lty = 1, lwd = 2)
```



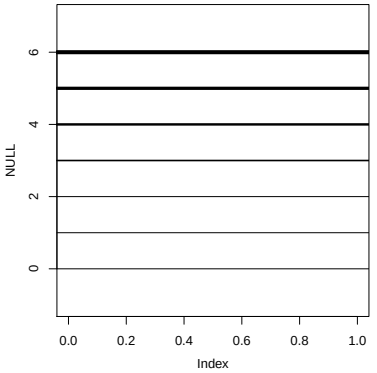
Traditional graphics: scatter plots

You can add lines to the plot:

```
plot(NULL, xlim = c(0, 1), ylim = c(-1, 7))
abline(h = 0, lty = 0, lwd = 2)
abline(h = 1, lty = 1, lwd = 2)
abline(h = 2, lty = 2, lwd = 2)
abline(h = 3, lty = 3, lwd = 2)
abline(h = 4, lty = 4, lwd = 2)
abline(h = 5, lty = 5, lwd = 2)
abline(h = 6, lty = 6, lwd = 2)
```



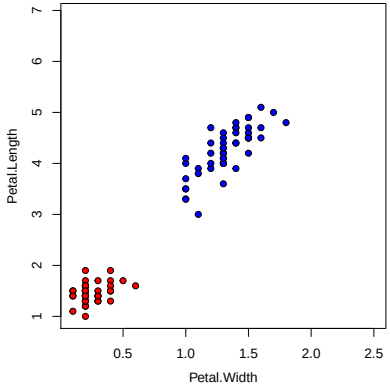

```
plot(NULL, xlim = c(0, 1), ylim = c(-1, 7))
abline(h = 0, lty = 1, lwd = 0.2)
abline(h = 1, lty = 1, lwd = 0.5)
abline(h = 2, lty = 1, lwd = 1)
abline(h = 3, lty = 1, lwd = 2)
abline(h = 4, lty = 1, lwd = 3)
abline(h = 5, lty = 1, lwd = 4)
abline(h = 6, lty = 1, lwd = 5)
```



Traditional graphics: scatter plots

You can also add additional points to the plot:

```
versicolor <- subset(iris, Species == "versicolor")
setosa     <- subset(iris, Species == "setosa")
plot(Petal.Length ~ Petal.Width, data = versicolor, pch = 21, bg = "blue", xlim = range(iris$Petal.Width), ylim = range(iris$Petal.Length))
points(Petal.Length ~ Petal.Width, data = setosa, pch = 21, bg = "red", xlim = range(iris$Petal.Width), ylim = range(iris$Petal.Length))
```

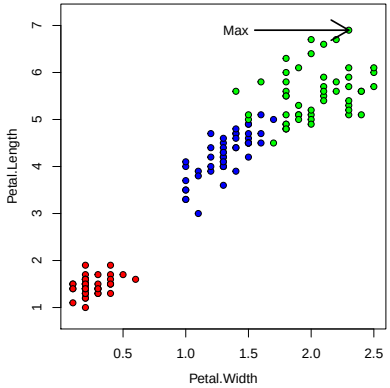


Note: You need to make sure the axis limits are the same!

Traditional graphics: scatter plots

You can add text and arrows:

```
palette(c("red", "blue", "green"))
plot(Petal.Length ~ Petal.Width, data = iris, pch = 21, bg = iris$Species, ylim = c(0.8, 7.2))
max.value <- iris[iris$Petal.Length == max(iris$Petal.Length), ]
arrows(x0 = max.value$Petal.Width - 0.75, y0 = max.value$Petal.Length,
       x1 = max.value$Petal.Width, y1 = max.value$Petal.Length, lwd = 2)
text(x = max.value$Petal.Width - 0.9, y = max.value$Petal.Length, labels = "Max")
```

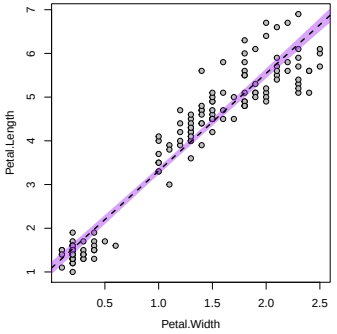


Traditional graphics: scatter plots

Including an interval around a prediction line requires you to build a polygon:

```
test_mod <- lm(Petal.Length ~ Petal.Width, data = iris)
newdat   <- data.frame(Petal.Width = seq(0, 3, length.out = 100))
pred     <- predict(test_mod, newdata = newdat, interval = "confidence")

plot(Petal.Length ~ Petal.Width, data = iris, pch = 21, bg = "grey")
polygon(x = c(newdat$Petal.Width, rev(newdat$Petal.Width)),
        y = c(pred[, "lwr"], rev(pred[, "upr"])),
        col = alpha("purple", alpha = 0.4),  ## alpha sets transparency!
        border = NA)  ## removes black line around the polygon
abline(test_mod, lty = 2, lwd = 2)
```



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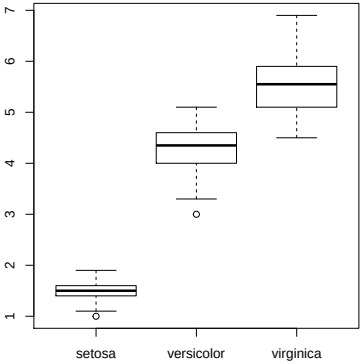
4. Conclusion: traditional graphics vs. `ggplot`

Traditional graphics: box plots

In traditional graphics, use `boxplot()` to draw a box plot:

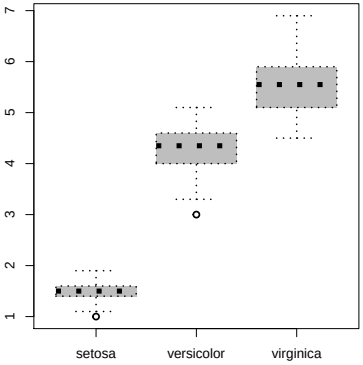
```
boxplot(Petal.Length ~ Species, data = iris)
```



Traditional graphics: box plots

Many of the same changes made to scatter plots can be made here:

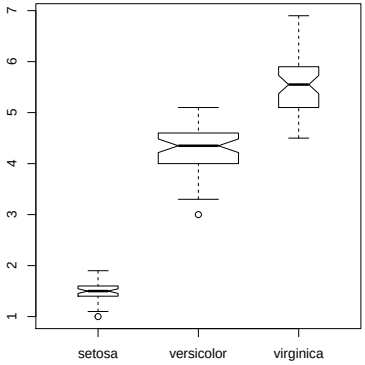
```
boxplot(Petal.Length ~ Species, data = iris, col = "grey", lwd = 2, lty = 3)
```



Traditional graphics: box plots

There are also some boxplot specific arguments:

```
boxplot(Petal.Length ~ Species, data = iris, width = c(1, 2, 1), notch = TRUE)
```



Traditional graphics: box plots

You can retrieve information by storing the output in an object:

```
my_boxcox <- boxplot(Petal.Length ~ Species, data = iris, plot = FALSE)

my_boxcox
## $stats
##      [,1] [,2] [,3]
## [1,]  1.1 3.30 4.50
## [2,]  1.4 4.00 5.10
## [3,]  1.5 4.35 5.55
## [4,]  1.6 4.60 5.90
## [5,]  1.9 5.10 6.90
##
## $n
## [1] 50 50 50
##
## $conf
##          [,1]     [,2]     [,3]
## [1,] 1.455311 4.215933 5.371243
## [2,] 1.544689 4.484067 5.728757
##
## $out
## [1] 1 3
##
## $group
## [1] 1 2
##
## $names
## [1] "setosa"     "versicolor" "virginica"
```

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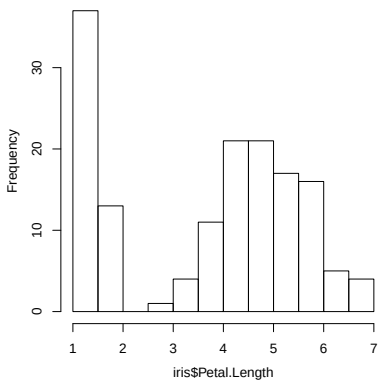
Traditional graphics: histograms

In traditional graphics, use `hist()` to draw an histogram:

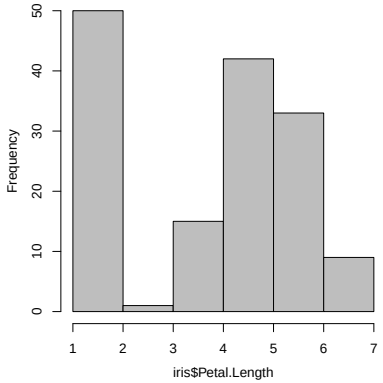
```
hist(iris$Petal.Length, main = "") ## main used here to remove the automatic title
```



Traditional graphics: histograms

You can change the number and location of breaks between bins:

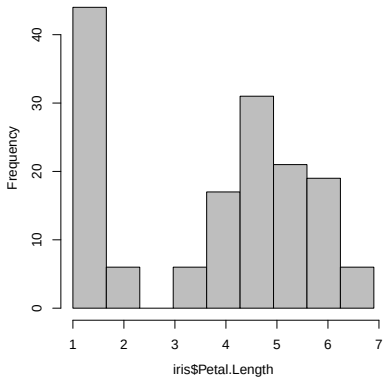
```
hist(iris$Petal.Length, main = "", breaks = 5, col = "grey")
```



Traditional graphics: histograms

You can change the number and location of breaks between bins:

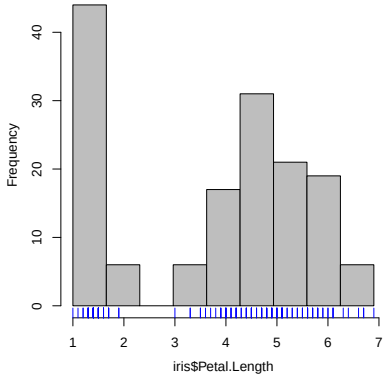
```
hist_breaks <- seq(min(iris$Petal.Length), max(iris$Petal.Length), length.out = 10)
hist(iris$Petal.Length, main = "", breaks = hist_breaks, col = "grey")
```



Traditional graphics: histograms

You can change the number and location of breaks between bins:

```
hist_breaks <- seq(min(iris$Petal.Length), max(iris$Petal.Length), length.out = 10)
hist(iris$Petal.Length, main = "", breaks = hist_breaks, col = "grey")
rug(x = iris$Petal.Length, col = "blue")
```



Note: it never hurts to add a rug under an histogram!

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Traditional graphics: bar plots

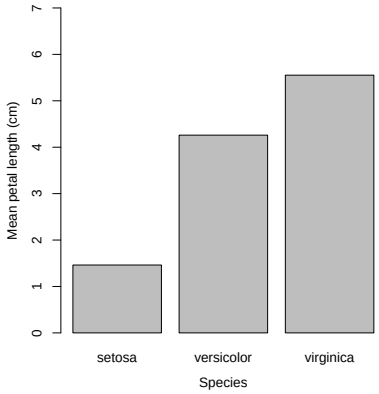
```
spp_means <- data.frame(Species = c("setosa", "versicolor", "virginica"),
                        mean = as.numeric(by(iris$Petal.Length, iris$Species, mean)),
                        SE = as.numeric(by(iris$Petal.Length, iris$Species, function(x)sd(x)/sqrt(length(x))))
                        )

spp_means
```

```
##      Species  mean         SE
## 1     setosa 1.462 0.02455980
## 2 versicolor 4.260 0.06645545
## 3  virginica 5.552 0.07804970
```

Traditional graphics: bar plots

In traditional graphics, use `barplot()` to draw a bar plot:

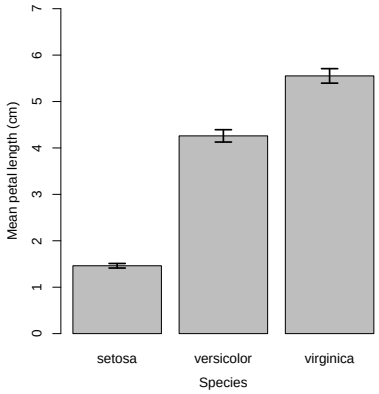
```
barplot(height = spp_means$mean, names.arg = spp_means$Species, ylim = c(0, 7),
        xlab = "Species", ylab = "Mean petal length (cm)")
```



Traditional graphics: bar plots

Adding error bars can be done with the arrows function:

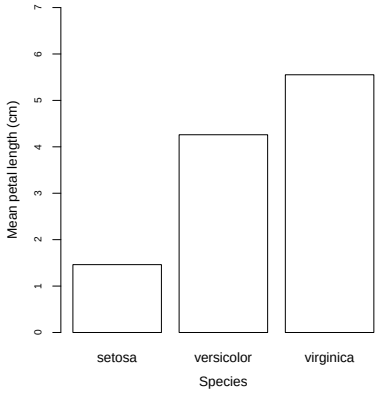
```
bar_locations <- barplot(height = spp_means$mean, names.arg = spp_means$Species, plot = FALSE)
barplot(height = spp_means$mean, names.arg = spp_means$Species, ylim = c(0, 7),
        xlab = "Species", ylab = "Mean petal length (cm)")
arrows(x0 = bar_locations[, 1], x1 = bar_locations[, 1],
       y0 = spp_means$mean - 2*spp_means$SE, y1 = spp_means$mean + 2*spp_means$SE,
       angle = 90, lwd = 2, code = 3, length = 0.1)
```



Traditional graphics: bar plots

As before, there are similar arguments available:

```
barplot(height = spp_means$mean, names.arg = spp_means$Species, ylim = c(0, 7),
        xlab = "Species", ylab = "Mean petal length (cm)",
        col = "white", cex.axis = 0.75)
```



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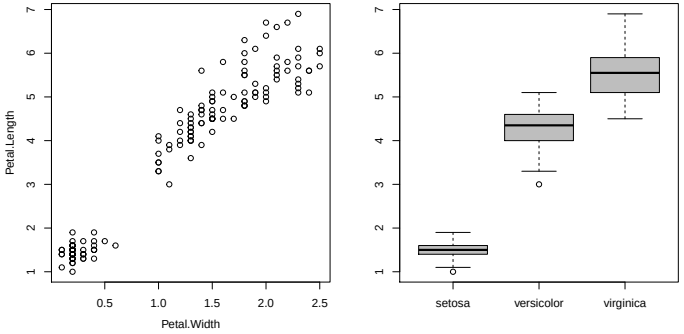
Combining plots

You can easily combine multiple traditional graphics using global parameters:

```
oldpar <- par(mfrow = c(1, 2))
plot(Petal.Length ~ Petal.Width, data = iris)
boxplot(Petal.Length ~ Species, data = iris, col = "grey")
```



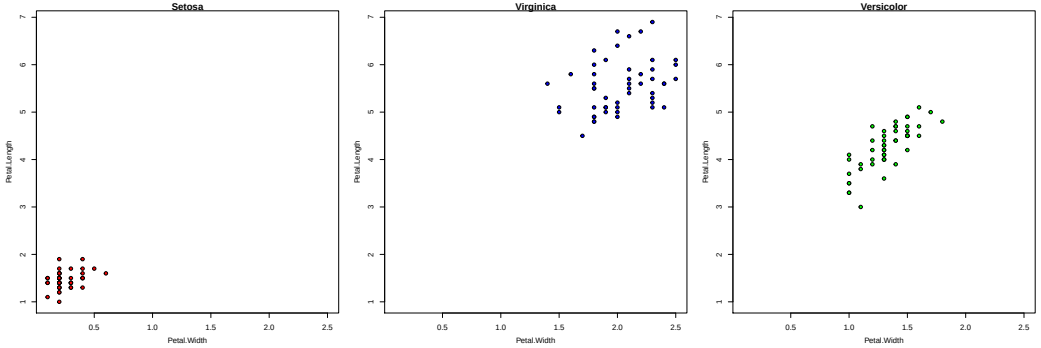

```
par(oldpar) ## restore default values
```

Note: if you want to combine graphics of different sizes it is a bit more complex (see `?layout`).

Facetting

This can be used to created 'facet' plots:

```
oldpar <- par(mfrow = c(1, 3))
split_data <- split(iris, iris$Species)
plot(Petal.Length ~ Petal.Width, data = split_data$setosa, main = "Setosa", pch = 21,
     bg = "red", col = "black", xlim = range(iris$Petal.Width), ylim = range(iris$Petal.Length))
plot(Petal.Length ~ Petal.Width, data = split_data$virginica, main = "Virginica", pch = 21,
     bg = "blue", col = "black", xlim = range(iris$Petal.Width), ylim = range(iris$Petal.Length))
plot(Petal.Length ~ Petal.Width, data = split_data$versicolor, main = "Versicolor", pch = 21,
     bg = "green", col = "black", xlim = range(iris$Petal.Width), ylim = range(iris$Petal.Length))
```

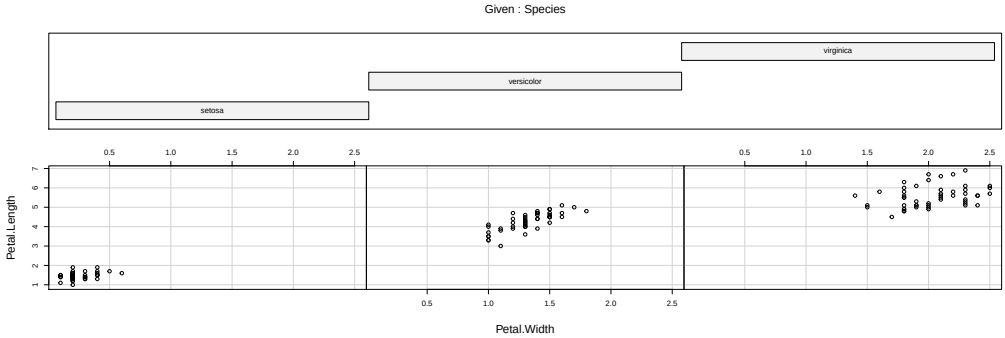



```
par(oldpar) ## restore default values
```

Facetting

Note: there is also an easier function for that:

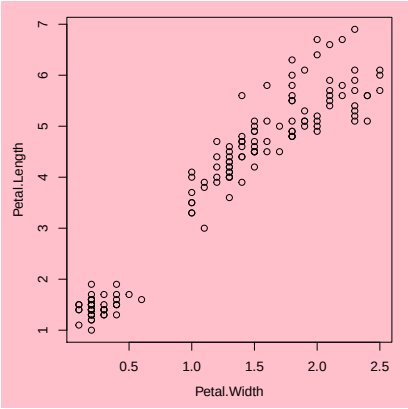
```
coplot(Petal.Length ~ Petal.Width | Species, data = iris, rows = 1)
```



Background

Global parameters can also be used to change the background colour:

```
oldpar <- par(bg = "pink")
plot(Petal.Length ~ Petal.Width, data = iris)
```



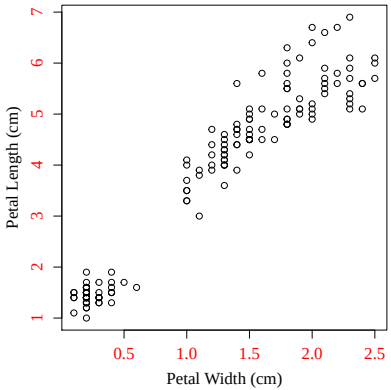

```
par(oldpar) ## restore default values
```

Note: you can also plot a background image but you need to use specific packages for that.

Modifying typefaces

Global parameters can also be used to change the typeface:

```
oldpar <- par(family = "serif")
plot(Petal.Length ~ Petal.Width, data = iris,
     xlab = "Petal Width (cm)", ylab = "Petal Length (cm)",
     cex.lab = 1.25, cex.axis = 1.25, col.axis = "red")
```

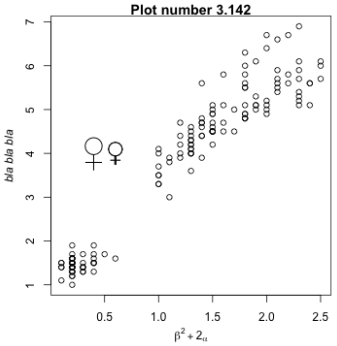



```
par(oldpar) ## restore default values
```

Special characters

You can use weird characters:

```
foo <- round(pi, 3)
plot(Petal.Length ~ Petal.Width, data = iris,
     xlab = expression(beta^2 + 2[alpha]), ylab = expression(paste(italic("bla bla bla"))),
     main = paste("Plot number", foo))
text(0.4, 4, "\u2640", cex = 3) ## requires font with unicode installed (try it!)
text(0.6, 4, "\\VE", vfont = c("serif", "plain"), cex = 3)
```

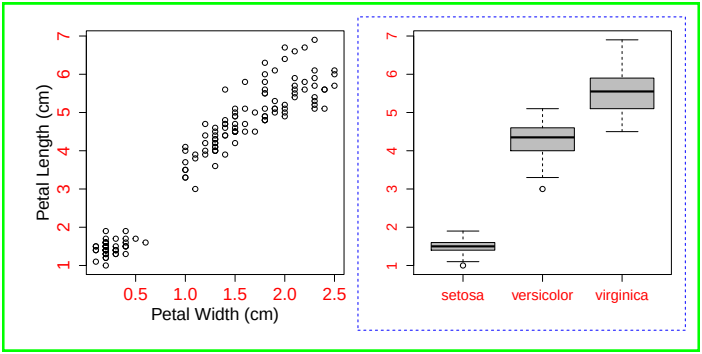


Note: unicode characters are nice but source of problems. How to make it work depends on both the OS, graphical device and typefaces installed on your computer.

Plot margins

Global parameters can also be used to change individual plot margins (blue) and outer margins (green):

```
oldpar <- par(mfrow = c(1, 2), mar = c(4, 4, 1, 1), oma = c(1.5, 2, 1, 1))
plot(Petal.Length ~ Petal.Width, data = iris,
     xlab = "Petal Width (cm)", ylab = "Petal Length (cm)",
     cex.lab = 1.5, cex.axis = 1.5, col.axis = "red")
boxplot(Petal.Length ~ Species, data = iris, col = "grey",
        cex.lab = 0.75, cex.axis = 1.25, col.axis = "red")
box('figure', col = 'blue', lty = "dashed")
box('outer', col = 'green', lwd = 5)
```

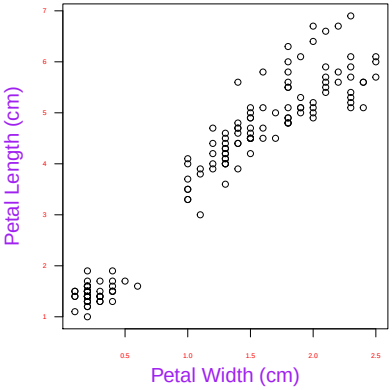



```
par(oldpar) ## restore default values
```

Change axes

You can change the size, colour and orientation of the axis labels and text easily:

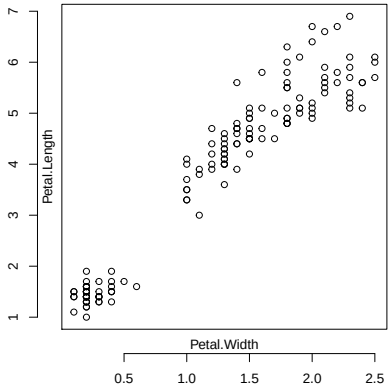
```
plot(Petal.Length ~ Petal.Width, data = iris,
     xlab = "Petal Width (cm)", ylab = "Petal Length (cm)",
     cex.lab = 1.5, cex.axis = 0.5, col.axis = "red", col.lab = "purple", las = 1)
```



Change axes

You can change the position of the axes:

```
oldpar <- par(mgp = c(0.4, 2, 1.5))
plot(Petal.Length ~ Petal.Width, data = iris)
```



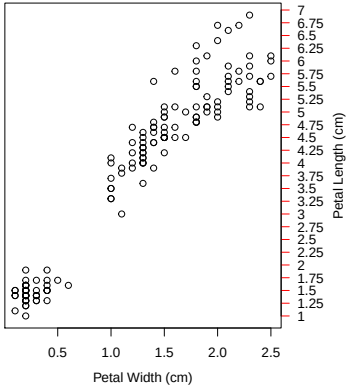

```
par(oldpar) ## restore default values
```

Note: check ?par for a huge list of the things you can easily change!

Change axes

You can change the axes themselves:

```
oldpar <- par(mar = c(4, 4, 1, 4))
plot(Petal.Length ~ Petal.Width, data = iris, axes = FALSE,
     xlab = "Petal Width (cm)", ylab = "")
axis(side = 1)
axis(side = 4, at = seq(1, 7, 0.25), labels =  seq(1, 7, 0.25), col.ticks = "red", las = 1)
mtext("Petal Length (cm)", side = 4, line = 3)
box()
```




```
par(oldpar) ## restore default values
```

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Traditional graphics: exporting

```
?pdf ?jpeg ?tiff ?bmp ?postscript
```

```
pdf("base_plot.pdf", width = 15, height = 5)
plot(Petal.Length ~ Petal.Width, data = iris)
dev.off()
```

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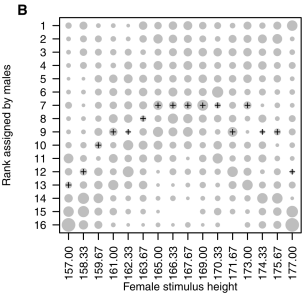
Challenge

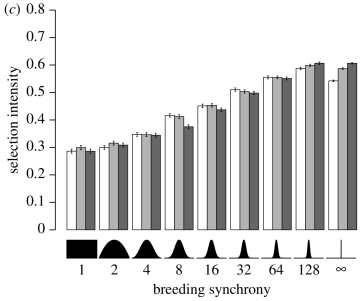
Run the examples of the following traditional plot functions:

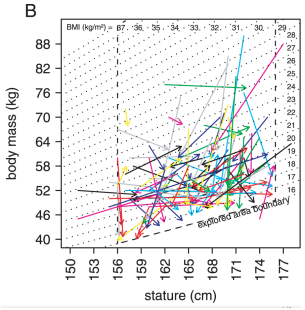
- `plot.ecdf()`
- `curve()`
- `pie()`
- `cdplot()`
- `image()`
- `contour()`
- `persp()`
- `dotchart()`
- `mosaicplot()`
- `stars()`
- `matplot()`
- `pairs()`
- `sunflowerplot()`

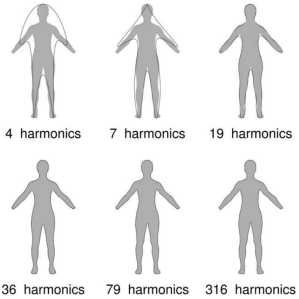
Note: there are a few other ones, but they do not seem very interesting...

You can create home-made **R** graphics too





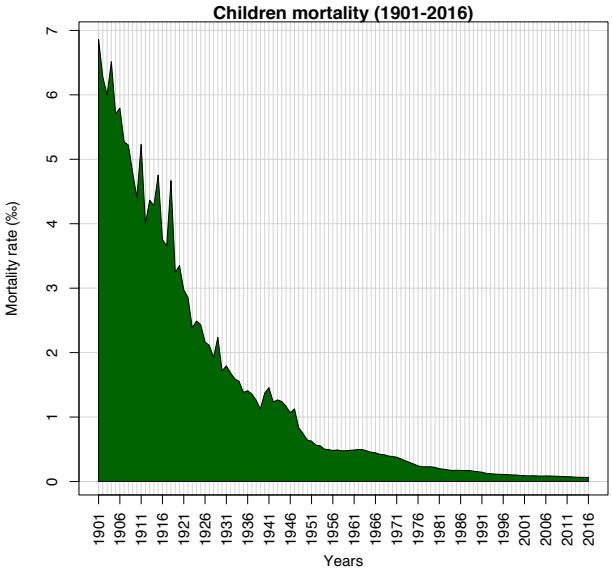




Challenge

Use the datasets called `population_UK` and `deaths_UK` to compute yearly mortality rates for individuals below 15 yrs only and make a really nice plot of the outcome!

Possible solution



Possible solution

```
library(dplyr)
deaths_processed <- deaths_UK %>%
  filter(Age_cat %in% levels(Age_cat)[1:3]) %>%
  group_by(Year) %>%
  summarize(tot_Deaths = sum(Deaths))

pop_processed <- population_UK %>%
  group_by(Year) %>%
  summarize(tot_Pop = sum(Pop))

data_processed <- full_join(deaths_processed, pop_processed) %>%
  mutate(rel_Deaths = 1000*tot_Deaths/tot_Pop)

par(mgp = c(3.2, 1, 0), mar = c(5, 5, 1, 1))

plot(rel_Deaths ~ Year, data = data_processed, col = NULL, axes = FALSE,
     ylab = "Mortality rate (\u2030)", xlab = "Years",
     main = paste0("Children mortality (", min(data_processed$Year), "-", max(data_processed$Year), ")"))

abline(v = seq(min(data_processed$Year), max(data_processed$Year), by = 1), col = "lightgrey", lwd = 0.5)
abline(h = 0:ceiling(max(data_processed$rel_Deaths)), col = "lightgrey", lwd = 0.5)

polygon(x = c(data_processed$Year, rev(x = data_processed$Year)),
        y = c(data_processed$rel_Deaths, rep(x = 0, times = nrow(data_processed))),
        col = "darkgreen")

axis(side = 1, at = seq(min(data_processed$Year), max(data_processed$Year), by = 5), las = 2)
axis(side = 2)
box()
```

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ggplot: introduction

ggplot (defunct) and ggplot2 were both created by Hadley Wickham (now chief Scientist at Rstudio) during his PhD: http://had.co.nz/thesis/practical-tools-hadley-wickham.pdf

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The idea was to create a grammar of graphics for **R**.

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In Wickham's words:
"The grammar of graphics is an answer to a question: what is a statistical graphic? [...] In brief, the grammar tells us that a statistical graphic is a mapping from data to aesthetic attributes (colour, shape, size) of geometric objects (points, lines, bars). The plot may also contain statistical transformations of the data and is drawn on a specific coordinate system. Facetting can be used to generate the same plot for different subsets of the dataset. It is the combination of these independent components that make up a graphic." (Wickham ggplot2 book)

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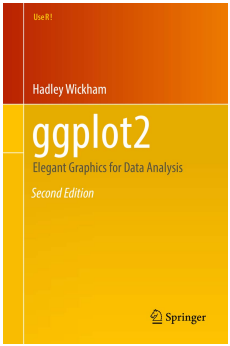
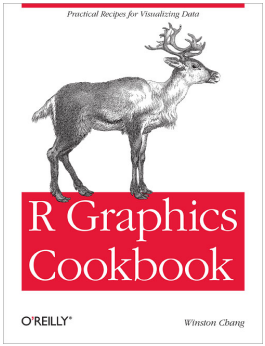
In plain english, that means that the graphics are build by considering building blocs or layers. The originality is that the user directly handles different functions corresponding to each layer and can combine them freely.

How to learn ggplot on your own?

- forum: `https://community.rstudio.com`
- reference:`http://ggplot2.tidyverse.org/reference/`
- the RStudio cheatsheet
- the books:





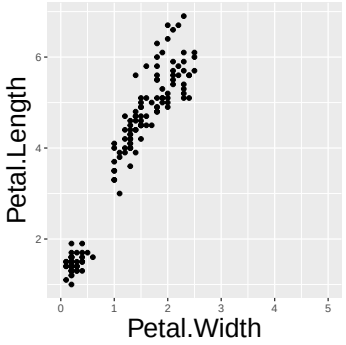
Note: Wickham's books (or their sources) are free and open source!

ggplot: introduction

Overall structure of a ggplot call:

```
library(ggplot2)

ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length)) + ## we specify the source of data and map the variables
  geom_point() + ## we use a function that specifies the type of plot (e.g. scatterplot, histogram). A geom_* function is always required!
  scale_x_continuous(limits = c(0, 5)) + ## we can fiddle with the scale_*_* functions to adjust the axes, colouration etc.
  theme(axis.title = element_text(size = 22)) # we can use one of the theme_* functions to change things like legends, font size etc.
```



Note: to better understand, execute the code progressively adding one command at a time!

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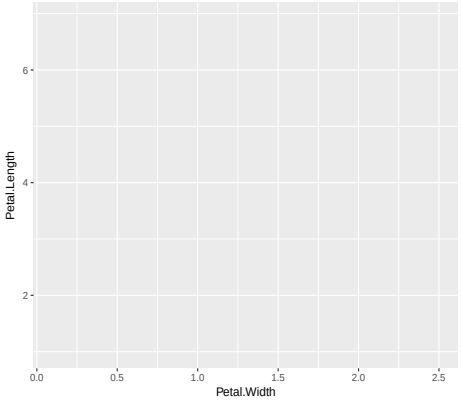
ggplot: scatter plots

We start by preparing the data:

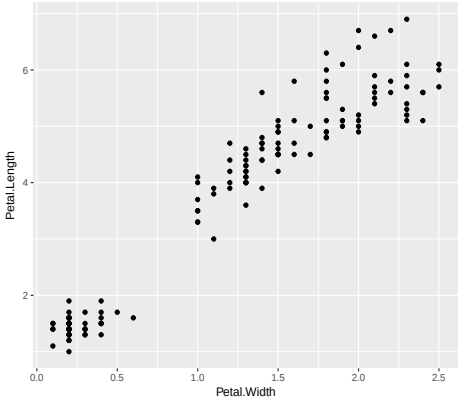
```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length))
```



ggplot: scatter plots

We add points on the empty plot:

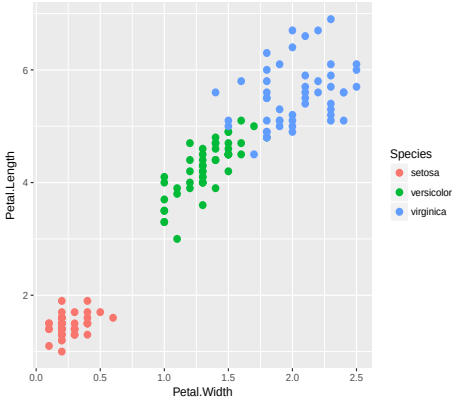
```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length)) + geom_point()
```



ggplot: scatter plots

You can change point shapes `shape` (= `pch` in traditional graphics) and `colour` (= `col` in traditional graphics):

```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length, colour = Species)) +
  geom_point(shape = 16, size = 3)
```

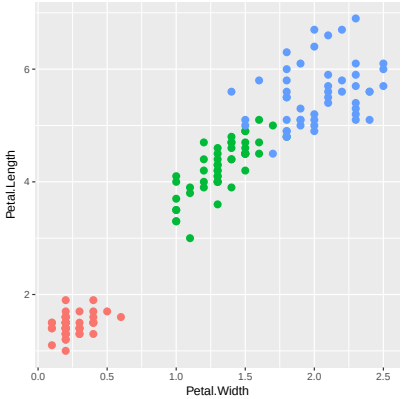


Note: everytime we want to create a connection between the data and some elements of the plot, we use the same function: `aes()`!

ggplot: scatter plots

In ggplot the legend is included by default but you can remove it:

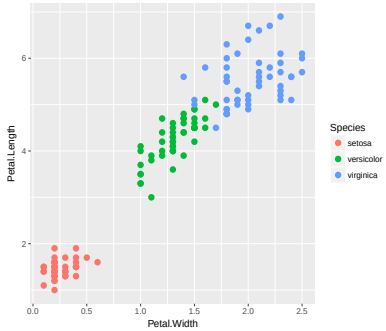
```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length, colour = Species)) +
  geom_point(shape = 16, size = 3) +
  theme(legend.position = "none")
```



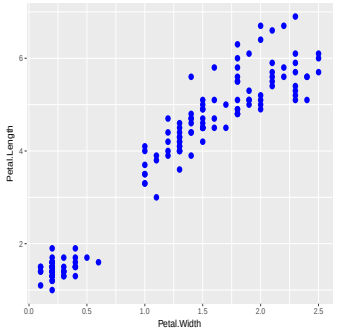
ggplot: scatter plots

The aesthetic function in ggplot is a powerful tool for changing plot aesthetics.
If you specify an aesthetic argument inside `aes()`, it will give each point a different aesthetic based on its value.
If you specify the same aesthetic argument outside `aes()`, it will give all data points the same aesthetic:

```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length,
                                  colour = Species)) +
  geom_point(shape = 16, size = 3)
```




```
ggplot(data = iris,
       mapping = aes(x = Petal.Width, y = Petal.Length)) +
  geom_point(colour = "blue", shape = 16, size = 3)
```

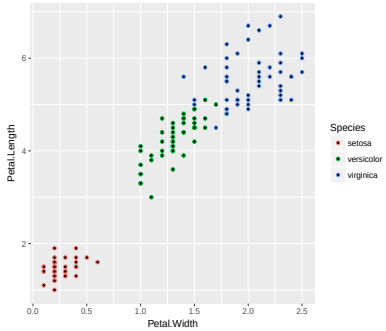


Note: we have used `aes()` to apply colours but it can be used to make other changes (see later).

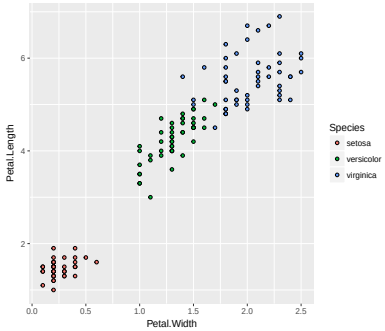
ggplot: scatter plots

Again, for many elements you can set both an outline `colour` (= `col` for traditional graphics) and background `fill` colour (= `bg` for traditional graphics):

```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length,
                                  colour = Species)) +
  geom_point(fill = "black", shape = 21)
```



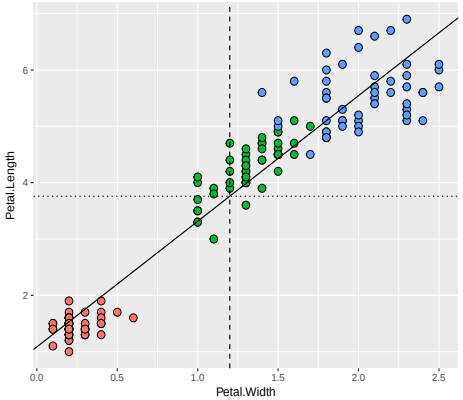

```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length,
                                  fill = Species)) +
  geom_point(colour = "black", shape = 21)
```



ggplot: scatter plots

You can also add lines to the plot:

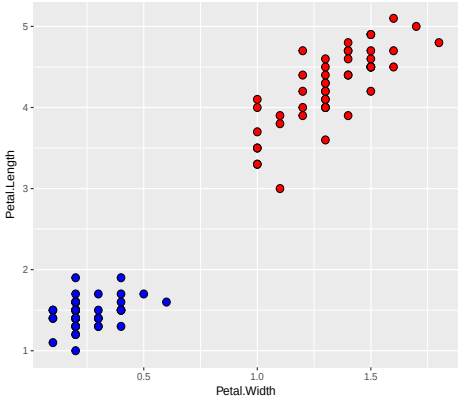
```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length, fill = Species)) +
  geom_point(shape = 21, size = 3) +
  theme(legend.position = "none") +
  geom_hline(yintercept = mean(x = iris$Petal.Length), lty = 3) +
  geom_vline(xintercept = mean(x = iris$Petal.Width), lty = 2) +
  geom_abline(intercept = 1.084, slope = 2.23, lty = 1)
```



ggplot: scatter plots

You can add extra points to the plot by using two geom_point layers:

```
versicolor <- subset(x = iris, Species == "versicolor")
setosa     <- subset(x = iris, Species == "setosa")
ggplot() +
  geom_point(data = versicolor, mapping = aes(x = Petal.Width, y = Petal.Length), fill = "red", shape = 21, size = 3) +
  geom_point(data = setosa, mapping = aes(x = Petal.Width, y = Petal.Length), fill = "blue", shape = 21, size = 3)
```

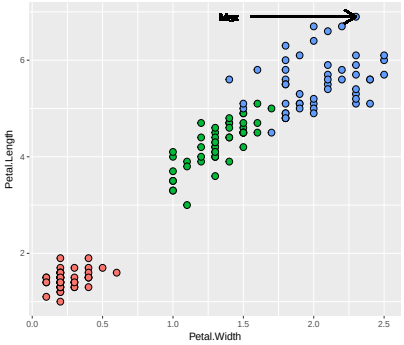


Note 1: unlike traditional plots, ggplot will automatically adjust the axes limits.
Note 2: if needed you can define the aes() in the geoms!!

Traditional graphics: scatter plots

You can add text and arrows:

```
max.value <- iris[iris$Petal.Length == max(iris$Petal.Length), ]
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length, fill = Species)) +
  geom_point(shape = 21, size = 3) +
  theme(legend.position = "none") +
  geom_segment(aes(x = max.value$Petal.Width - 0.75,
                   xend = max.value$Petal.Width,
                   y = max.value$Petal.Length,
                   yend = max.value$Petal.Length), size = 1,
               arrow = arrow(length = unit(0.5, "cm"))) +
  geom_text(mapping = aes(x = max.value$Petal.Width - 0.9, y = max.value$Petal.Length, label = "Max"))
```

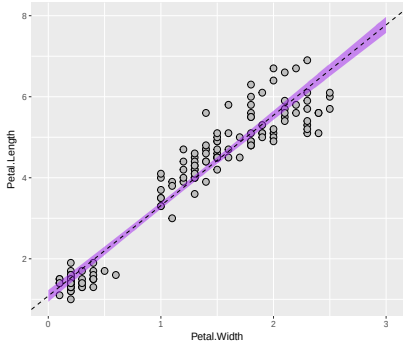


ggplot: scatter plots

In ggplot, confidence intervals can be added with specialised function `geom_ribbon()`:

```
test_mod <- lm(Petal.Length ~ Petal.Width, data = iris)
newdat   <- data.frame(Petal.Width = seq(0, 3, length.out = 100))
pred     <- predict(test_mod, newdata = newdat, interval = "confidence")

ggplot() +
  geom_point(data = iris,    mapping = aes(x = Petal.Width, y = Petal.Length), fill = "grey", shape = 21, size = 3) +
  geom_ribbon(data = newdat, mapping = aes(x = Petal.Width, ymin = pred[, 2], ymax = pred[, 3]), fill = "purple", alpha = 0.5) +
  geom_abline(intercept = coef(test_mod)[1], slope = coef(test_mod)[2], lty = 2)
```

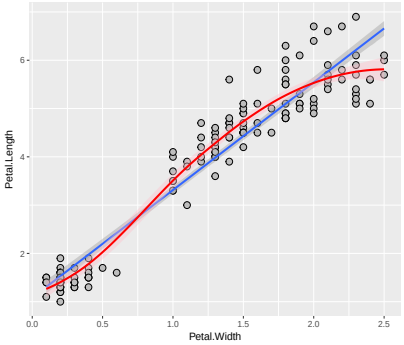


Note: because we are building the plot with two different datasets (i.e. `iris` & `newdat`), we specify the `data` and `aes()` separately in each line of the ggplot code.

ggplot: scatter plots

In ggplot, you can also do basic statistics directly:

```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length)) +
  geom_point(fill = "grey", shape = 21, size = 3) +
  geom_smooth(method = "lm") +
  geom_smooth(method = "loess", fill = "pink", colour = "red")
```



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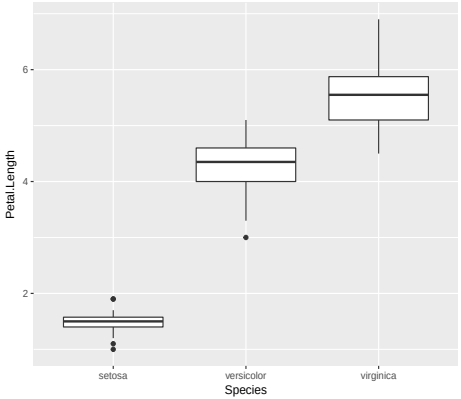
ggplot: box plots

In ggplot, use `geom_boxplot()` to draw a box plot:

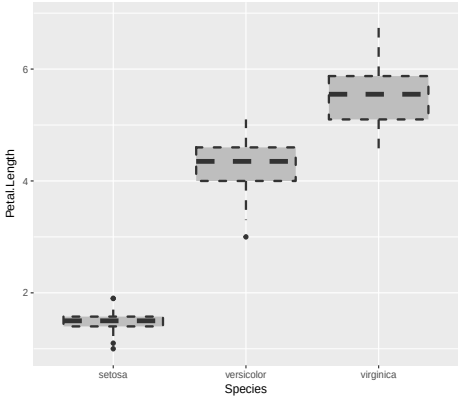
```
ggplot(data = iris, mapping = aes(x = Species, y = Petal.Length)) +
  geom_boxplot()
```



ggplot: box plots

Many of the same changes made to scatter plots can be made here:

```
ggplot(data = iris, mapping = aes(x = Species, y = Petal.Length)) +
  geom_boxplot(fill = "grey", size = 1, lty = 2)
```



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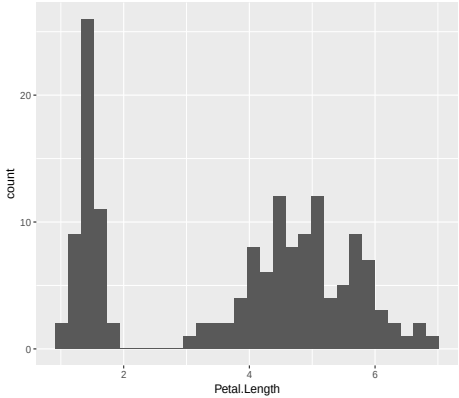
ggplot: histograms

In ggplot, use `geom_histogram()` to draw an histogram:

```
ggplot(data = iris, mapping = aes(x = Petal.Length)) +
  geom_histogram()
```

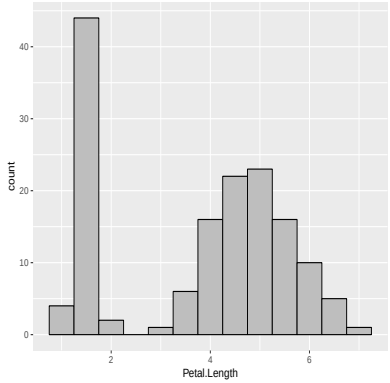
```
## `stat_bin()` using `bins = 30`.  Pick better value with
## `binwidth`.
```



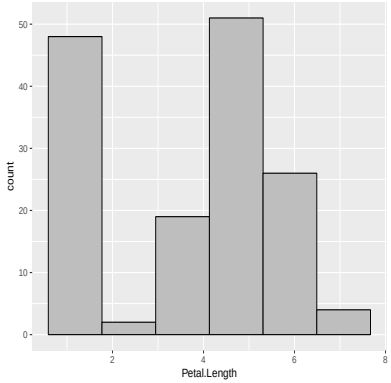
ggplot: histograms

You can change the width of bins with `binwidth` or their number with `bins`:

```
ggplot(data = iris, mapping = aes(x = Petal.Length)) +
  geom_histogram(binwidth = 0.5, colour = "black", fill = "grey")
```



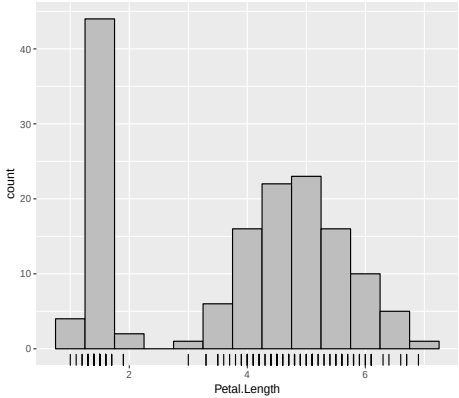

```
ggplot(data = iris, mapping = aes(x = Petal.Length)) +
  geom_histogram(bins = 6, colour = "black", fill = "grey")
```



ggplot: histograms

Add a rug below the histogram with geom_rug:

```
ggplot(data = iris, mapping = aes(x = Petal.Length)) +
  geom_histogram(binwidth = 0.5, colour = "black", fill = "grey") +
  geom_rug()
```



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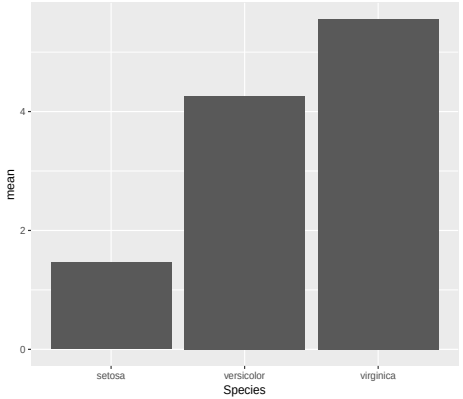
ggplot: bar plots

In ggplot, use `geom_col()` to draw a bar plot:

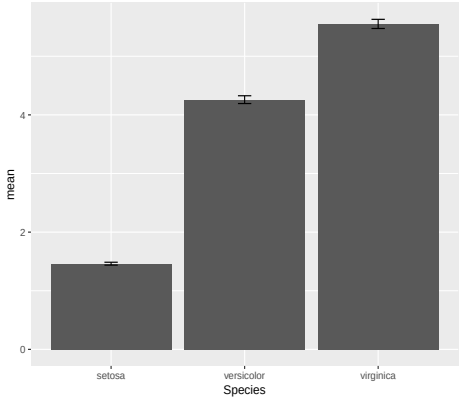
```
ggplot(data = spp_means, mapping = aes(x = Species, y = mean)) +
  geom_col()
```



ggplot: bar plots

Adding error bars in ggplot is much easier than in traditional graphics:

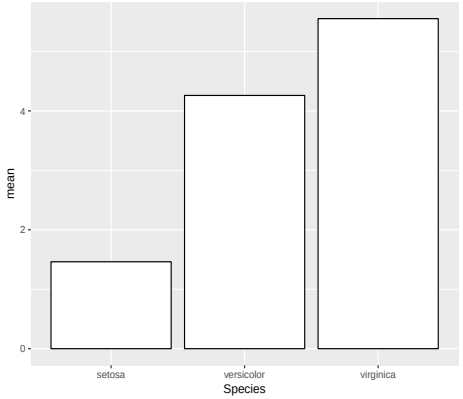
```
ggplot(data = spp_means, mapping = aes(x = Species, y = mean)) +
  geom_col() +
  geom_errorbar(aes(ymin = mean - SE, ymax = mean + SE), width = 0.1)
```



ggplot: bar plots

As before, modifications are straigthforward:

```
ggplot(data = spp_means, mapping = aes(x = Species, y = mean)) +
  geom_col(fill = "white", colour = "black")
```



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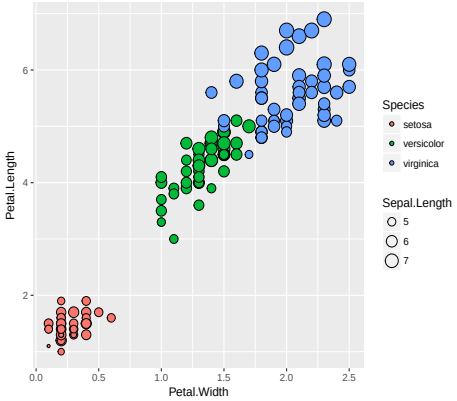
Introduction to aesthetics

In ggplot, you can change aesthetics in individual segments of the code (`aes()`) *or* you can change information for the whole plot using themes (`theme()`).

Using the aesthetic function more

We'll start by looking back at `aes()`.
We can use it to change multiple aesthetics of a plot:

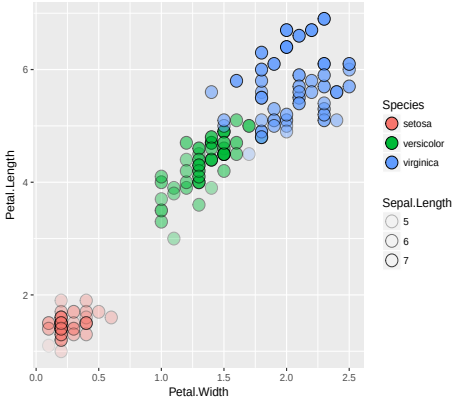
```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length, fill = Species, size = Sepal.Length)) +
  geom_point(shape = 21)
```



Using the aesthetic function more

Here we change the transparency:

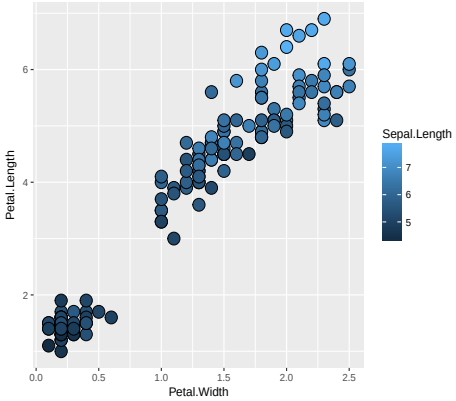
```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length, fill = Species, alpha = Sepal.Length)) +
  geom_point(shape = 21, size = 5)
```



Using the aesthetic argument more

Applying aesthetics to continuous variables will be different to categorical variables:

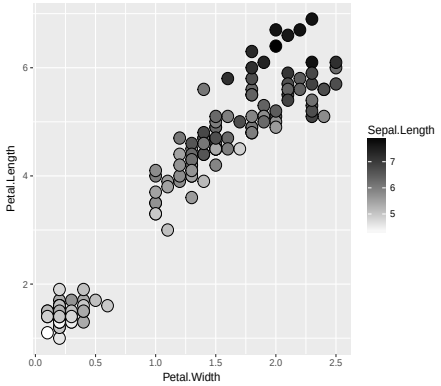
```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length, fill = Sepal.Length)) +
  geom_point(shape = 21, size = 5)
```



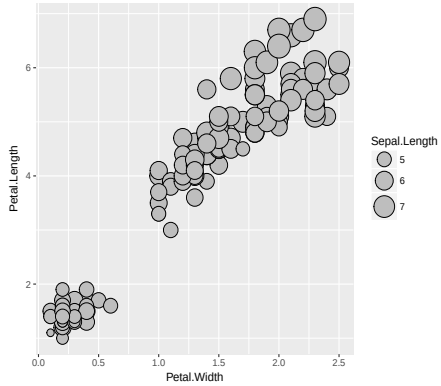
Using the aesthetic argument more

You can indicate values for a third dimension in different ways:

```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length,
                                  fill = Sepal.Length)) +
  geom_point(shape = 21, size = 5) +
  scale_fill_continuous(low = "white", high = "black")
```



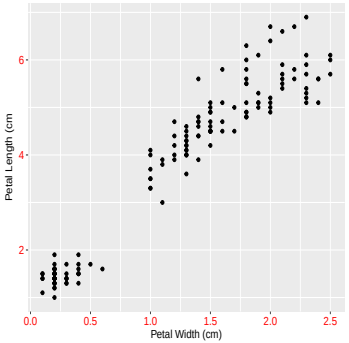

```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length,
                                  size = Sepal.Length)) +
  geom_point(shape = 21, fill = "grey") +
  scale_size_continuous(range = c(3, 10))
```



Change text

You can change size and colour of axis text easily:

```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length)) +
  geom_point() +
  xlab("Petal Width (cm)") +
  ylab("Petal Length (cm") +
  theme(axis.text = element_text(size = 12, colour = "red"), axis.title = element_text(size = 12))
```



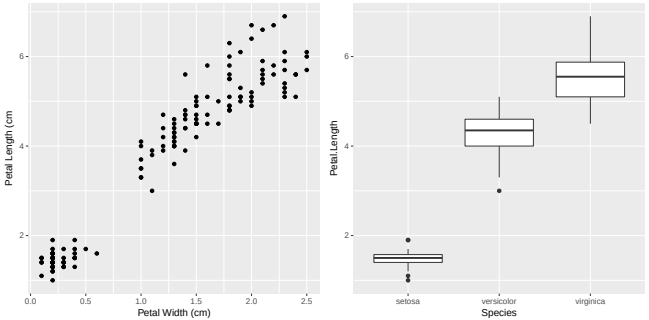
Note: the text size uses different measurement units than traditional graphics.

Combining plots

Combining plots is less straightforward in ggplot...

You need to use an additional package:

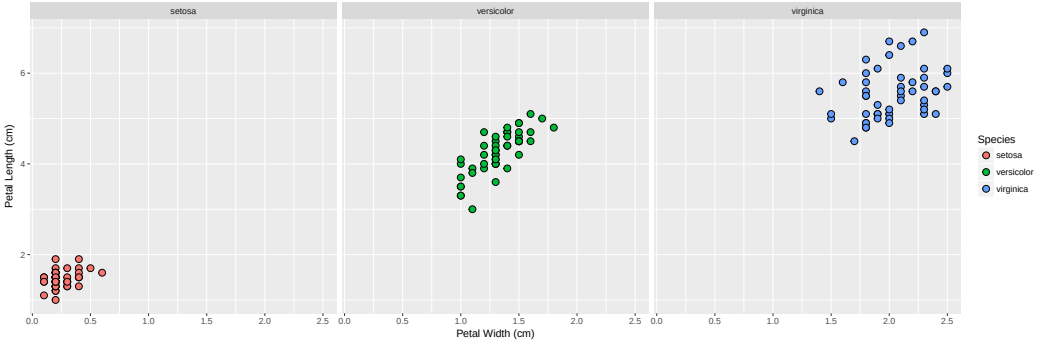
```
scatter <- ggplot(iris, mapping = aes(x = Petal.Width, y = Petal.Length)) + geom_point() +
  xlab("Petal Width (cm)") + ylab("Petal Length (cm")

box     <- ggplot(iris, mapping = aes(x = Species, y = Petal.Length)) + geom_boxplot()

library(gridExtra)
grid.arrange(scatter, box, nrow = 1)
```



Faceting

Although combining multiple plots is cumbersome, there is an inbuilt function to create facets:

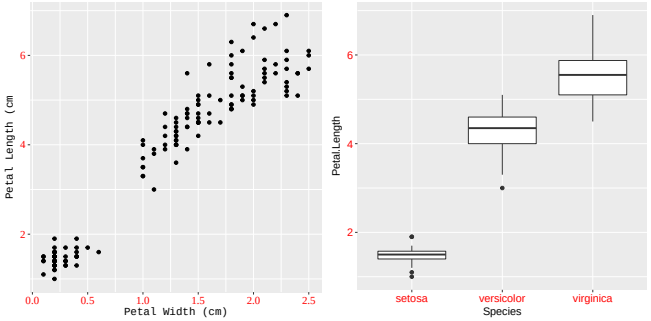
```
ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length, fill = Species)) +
  geom_point(shape = 21, colour = "black", size = 3) +
  xlab("Petal Width (cm)") +
  ylab("Petal Length (cm)") +
  facet_wrap(~ Species)
```



Modifying typefaces

Unlike traditional graphics, in ggplot you can easily change the typeface of individual elements in theme:

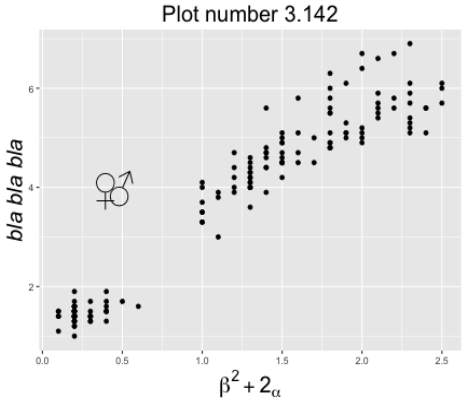
```
scatter <- ggplot(data = iris, mapping = aes(x = Petal.Width, y = Petal.Length)) +
  geom_point() +
  xlab("Petal Width (cm)") +
  ylab("Petal Length (cm)") +
  theme(axis.text = element_text(size = 12, colour = "red", family = "serif"), axis.title = element_text(size = 12, family = "mono"))

box     <- ggplot(iris, mapping = aes(x = Species, y = Petal.Length)) +
  geom_boxplot() +
  theme(axis.text = element_text(size = 12, colour = "red", family = "sans"), axis.title = element_text(size = 12, family = "sans"))

grid.arrange(scatter, box, nrow = 1)
```



Special characters

You can use weird characters:

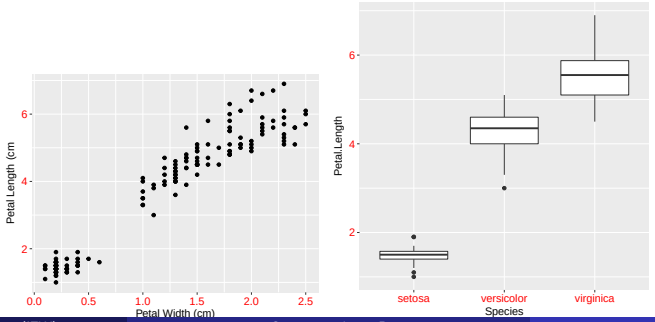
```
foo <- round(pi, 3)
ggplot(iris, mapping = aes(x = Petal.Width, y = Petal.Length)) +
  geom_point() +
  labs(x = expression(beta^2 + 2[alpha]), y = expression(paste(italic("bla bla bla"))), title = paste("Plot number", foo)) +
  annotate("text", x = c(0.4, 0.5), y = c(4, 4), label = c("\u2640", "\u2642"), size = 12) + ## requires font with unicode installed (try it
  theme(plot.title = element_text(hjust = 0.5, size = 20),
        axis.title = element_text(size = 20))
```



Plot margins

Plot margins are also controlled in theme of each plot individually:

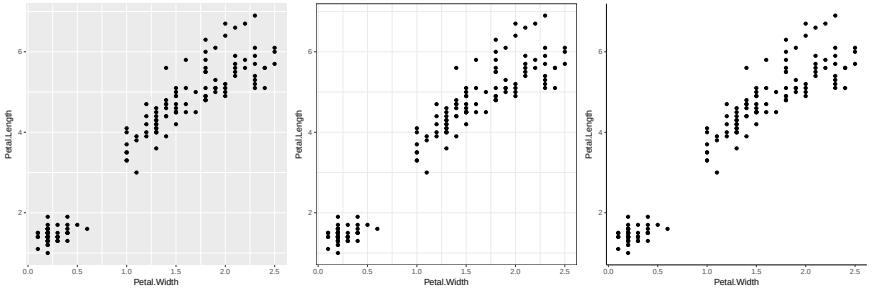
```
scatter <- ggplot(data = iris, aes(x = Petal.Width, y = Petal.Length)) +
           geom_point() +
           xlab("Petal Width (cm)") +
           ylab("Petal Length (cm") +
           theme(axis.text = element_text(size = 12, colour = "red"),
                 axis.title = element_text(size = 12),
                 plot.margin = unit(c(30, 4, 1, 1), "mm"))

box     <- ggplot(iris, aes(x = Species, y = Petal.Length)) +
           geom_boxplot() +
           theme(axis.text = element_text(size = 12, colour = "red"),
                 axis.title = element_text(size = 12))

grid.arrange(scatter, box, nrow = 1)
```



Preset themes

ggplot also has a number of preset themes that you can use:

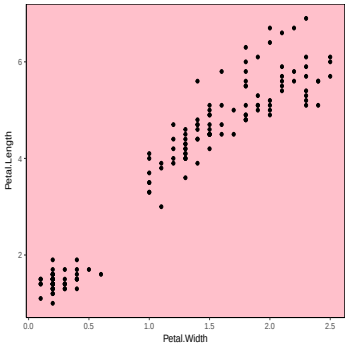
```
grey <- ggplot(data = iris, aes(x = Petal.Width, y = Petal.Length)) +
  geom_point() +
  theme_grey()

bw <- ggplot(data = iris, aes(x = Petal.Width, y = Petal.Length)) +
  geom_point() +
  theme_bw()

classic <- ggplot(data = iris, aes(x = Petal.Width, y = Petal.Length)) +
  geom_point() +
  theme_classic()

grid.arrange(grey, bw, classic, nrow = 1)
```



Preset themes

You can create your own theme once for all!

```
theme_pink <- theme_classic() %+replace% theme(panel.background = element_rect(fill = "pink"))

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

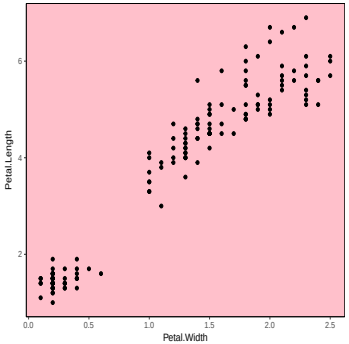


Note: check `?theme` for the list of options that can be changed.

Preset themes

You can set a theme for all plots with `theme_set`

```
theme_old  <- theme_set(theme_pink)

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




```
theme_set(theme_old) ## restore original theme
```

Plotting in **R**

1. Introduction
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   - scatter plot
   - box plots
   - histograms
   - bar plots
   - aesthetics
   - saving your plot
   - other plots
3. Plotting with ggplot
   - introduction
   - scatter plots
   - box plots
   - histograms
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   - saving your plot
   - other plots
4. Conclusion: traditional graphics vs. ggplot

ggplot: Exporting

```
?ggsave
```

```
classic <- ggplot(iris, aes(x = Petal.Width, y = Petal.Length))+
  geom_point()+
  theme_classic()

ggsave("ggplot.pdf", plot = classic, width = 15, height = 5)
```

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There are other geom out there!

There are a few other plot types in ggplot that are worth looking at (check the cheatsheet!):

- `geom_violin()`
- `geom_area()`
- `geom_smooth()`
- `geom_density()`

There are other geom out there!

There are a few other plot types in ggplot that are worth looking at (check the cheatsheet!):

- `geom_violin()`
- `geom_area()`
- `geom_smooth()`
- `geom_density()`

But the true force of having developed something as modular as ggplot is that there are many more packages each week providing ggplot extensions!

A few random examples of ggplot extensions:

- ggExtra (for marginal distribution)
- ggthemes (for extra themes, including `theme_excel()`!! :-/)
- ggmap (for maps)
- ggrepel (for adding labels to plots)
- ggalt (for creating cluster plots)
- cowplot (for creating nested figures)

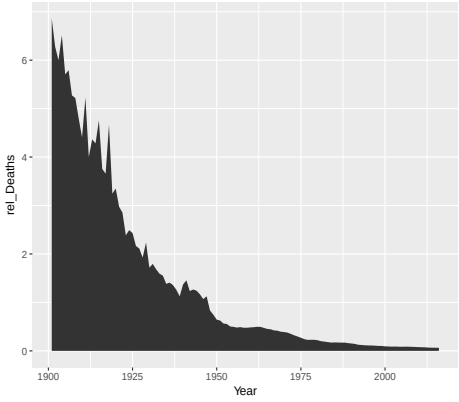
Note: see also `http://www.ggplot2-exts.org/gallery/` (but the list is incomplete).

Challenge

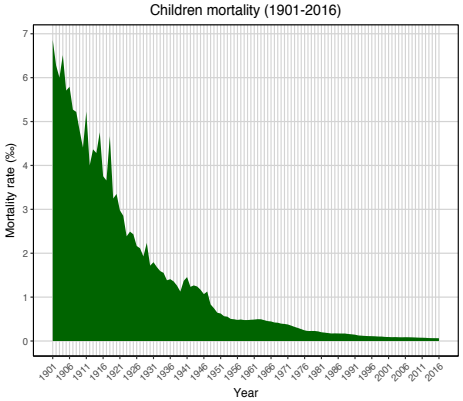
Use the datasets called `population_UK` and `deaths_UK` to compute yearly mortality rates for individuals below 15 yrs only and make a nice plot of the outcome using `ggplot2`!

Simple solution

```
ggplot(data = data_processed, mapping = aes(y = rel_Deaths, x = Year)) + geom_area()
```



More complex solution



More complex solution

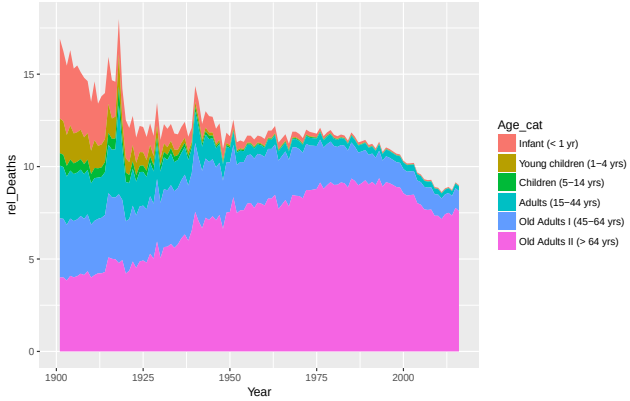
```
ggplot(data = data_processed, mapping = aes(y = rel_Deaths, x = Year)) +
  geom_area(fill = "darkgreen") +
  ylab("Mortality rate (\u2030)") +
  labs(title = paste0("Children mortality (", min(data_processed$Year), "-", max(data_processed$Year), ")")) +
  scale_x_continuous(breaks = seq(min(data_processed$Year), max(data_processed$Year), by = 5),
                     minor_breaks = min(data_processed$Year):max(data_processed$Year)) +
  scale_y_continuous(breaks = 0:ceiling(max(data_processed$Year)),
                     minor_breaks = NULL) +
  theme_classic() +
  theme(axis.text.x = element_text(angle = 45, hjust = 1), plot.title = element_text(hjust = 0.5),
        panel.grid.minor = element_line(colour = "lightgrey"),
        panel.grid.major = element_line(colour = "lightgrey"),
        panel.border = element_rect(colour = "black", fill = NA))
```

Challenge

Use the datasets called `population_UK` and `deaths_UK` to compute yearly mortality rates for individuals of each age class and make a quick plot of the outcome using `ggplot2`!

Possible solution

```
deaths_processed_all <- deaths_UK %>% group_by(Year, Age_cat) %>% summarize(tot_Deaths = sum(Deaths))
pop_processed <- population_UK %>% group_by(Year) %>% summarize(tot_Pop = sum(Pop)) ## as before
data_processed_all <- full_join(deaths_processed_all, pop_processed) %>% mutate(rel_Deaths = 1000*tot_Deaths/tot_Pop)
## Joining, by = "Year"
ggplot(data = data_processed_all, mapping = aes(y = rel_Deaths, x = Year, fill = Age_cat)) + geom_area()
```



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Which plotting tool should you use?

Traditional graphics:

- no new packages required
- arguments often differ between functions
- help files useful
- easier for doing something simple
- more difficult for doing something complex
- main restriction: always add things on top of what has already been plotted

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ggplot:

- requires multiple packages for best results
- uniform grammar
- help files often useless (due to modularity)
- more difficult for doing something simple
- easier for doing something complex
- faster for large datasets
- more accessible than lattice

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$\rightarrow$ It may be useful to know both!!