Basic plotting in R - histograms, boxplots, scatterplots

Introduction to data science (DSC 105) Fall 2022

Table of Contents

1 Histograms

- `[ ]`

  When do you think of using **barplots**?

  > Barplots are sensible for counting **observations of categories**

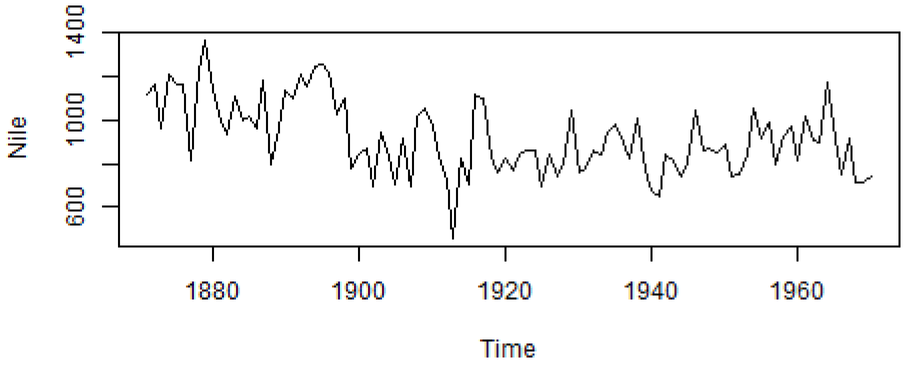
- `[ ]`

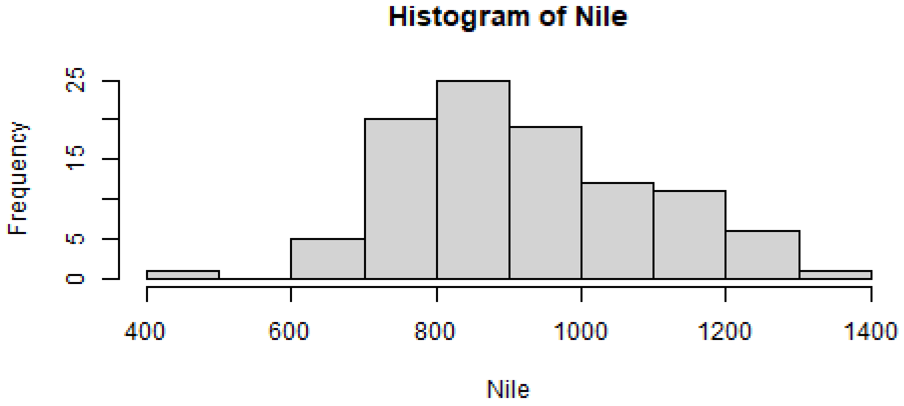
  When do you think of using a **histogram**?

  > When you have observed a single **numeric-continuous variable**

- *Example:* You've already seen the histogram for a simple data structure, the **time series** `ts` (here next to the **line plot**):

  ```
  par(mfrow=c(2,1)) # create 2 x 1 plot array
  plot(Nile)
  hist(Nile)
  ```





- [ ]

  What does the *height* of a bar represent exactly?

  > The height of each bar (on the y-axis) represents the number of years in which the volume of water flowing through the Nile was within its interval of 100 mio cubic metres width (on the x-axis).

- [ ]

  How can you find out what the *binwidth* of this histogram is?

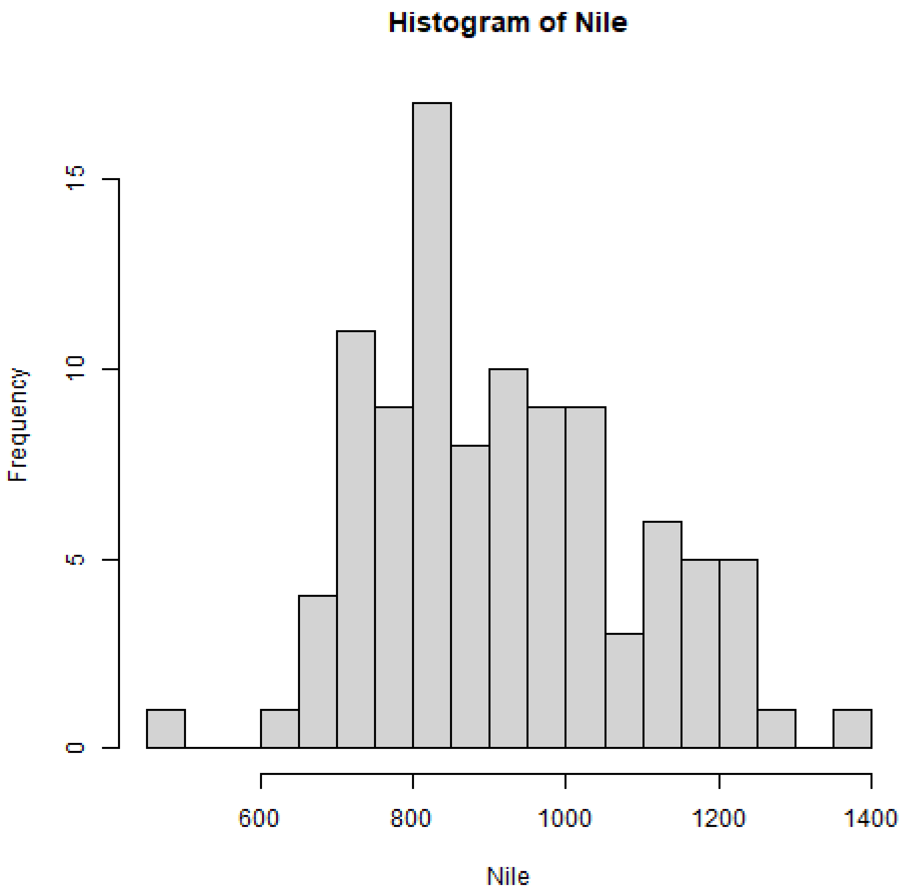
```
str(hist(Nile))
```

```
List of 6
 $ breaks  : int [1:11] 400 500 600 700 800 900 1000 1100 1200 1300 ...
 $ counts  : int [1:10] 1 0 5 20 25 19 12 11 6 1
 $ density : num [1:10] 0.0001 0 0.0005 0.002 0.0025 0.0019 0.0012 0.0011 0.0006 0.0001
 $ mids    : num [1:10] 450 550 650 750 850 950 1050 1150 1250 1350
 $ xname   : chr "Nile"
 $ equidist: logi TRUE
 - attr(*, "class")= chr "histogram"
```

- [ ]

  Look at the help for hist, then change the binwidth to 30.

  ```
  hist(Nile, breaks=30)
  ```

- [ ]

  How can you **print** the value for the binwidth (breaks)?

  ```
  h <- hist(Nile)
  h$breaks[2]-h$breaks[1]
  ```

  ```
  [1] 100
  ```

- [ ]

  What happens when you choose breaks=0?

  ```
  hist(Nile, breaks=0)
  ```

```
Error in hist.default(Nile, breaks = 0) : invalid number of 'breaks'
```

- [ ]

  What happens when you set `breaks=1000001` (`1e+6 + 1`)?

  ```
  hist(Nile, breaks=1000001)
  ```

  ```
  Warning message:
  In hist.default(Nile, breaks = 1000001) :
    'breaks = 1e+06' is too large and set to 1e6
  ```

- [ ]

  Create a script file `Nile.R`, put the previous command into it, and run it as a batch process in the shell (using `M-x eshell`):

  ```
  $ R CMD BATCH Nile.R
  ```

  Open the output file `Nile.rout` to see the result:

  ```
  > hist(Nile, breaks=1000001)
  Warning message:
  In hist.default(Nile, breaks = 1000001) :
  'breaks = 1e+06' is too large and set to 1e6
  >
  > proc.time()
    user  system elapsed
    1.09    0.09    1.20
  ```

- `proc.time` and `system.time` measure the performance of R. Example: measure rolling 1 die a million times:

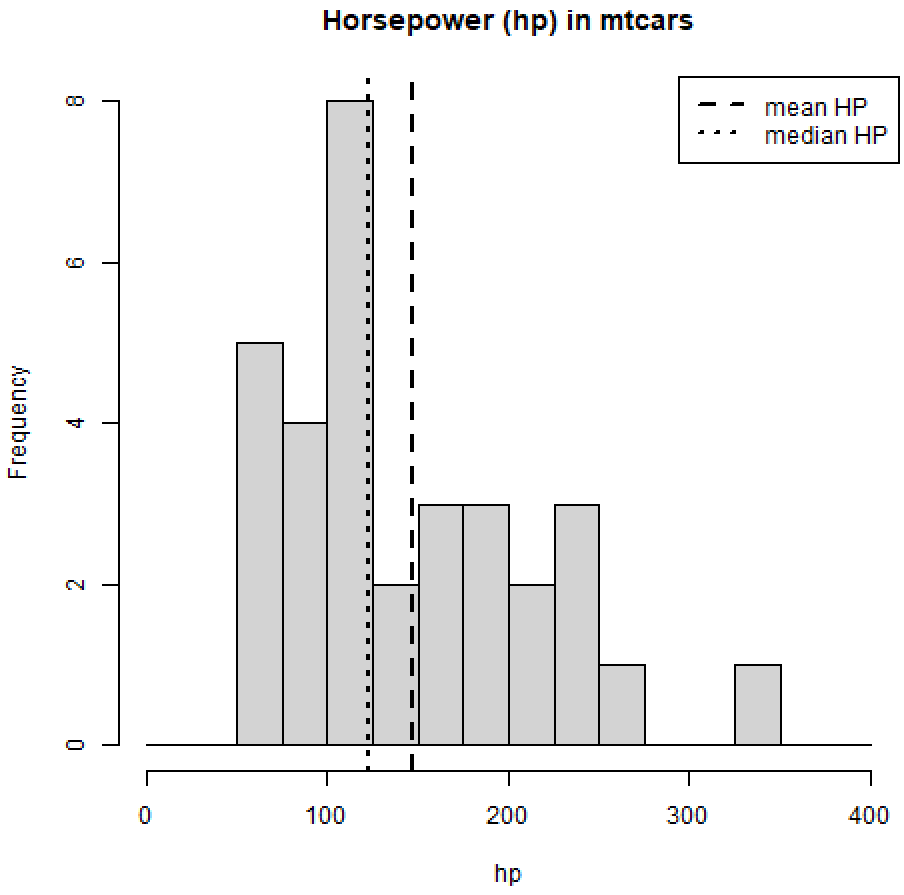
  ```
  system.time(
    for (i in 1:1e6)
      sample(1:6,1))
  ```

  ```
  user  system elapsed
  4.29    0.51    4.83
  ```

2 Histogram analysis

- You can manually set the histogram `breaks` by supplying a vector
- Example: horsepower `hp` in the `mtcars` dataset with `breaks` from `0` to `400`, `25` units apart from each other:

```
hp <- mtcars$hp
hist(x=hp,
     breaks=seq(from=0, to=400, by=25),
     main="Horsepower (hp) in mtcars")  # histogram
abline(v=c(mean(hp),median(hp)),
       lty=c(2,3),lwd=2) # mean, median
legend("topright",
       legend=c("mean HP","median HP"),
       lty=c(2,3),lwd=2) # legend
```



- Reducing the bin width allows seeing more detail but also risks highlighting irrelevant features (like the single outlying car).

```
max(hp) # outlier in mtcars$hp
```

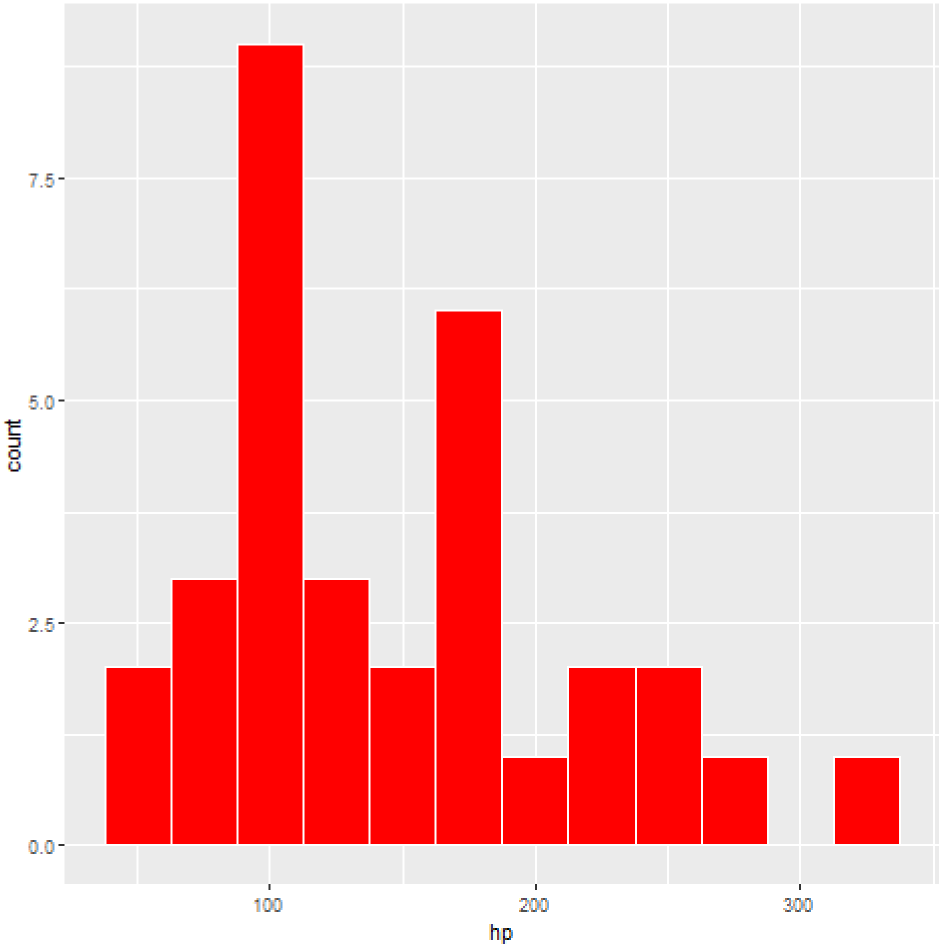
```
[1] 335
```

- Too small a binwidth leads to too much detail
- Too large a binwidth leads to loss of detail

3 Histograms in ggplot2

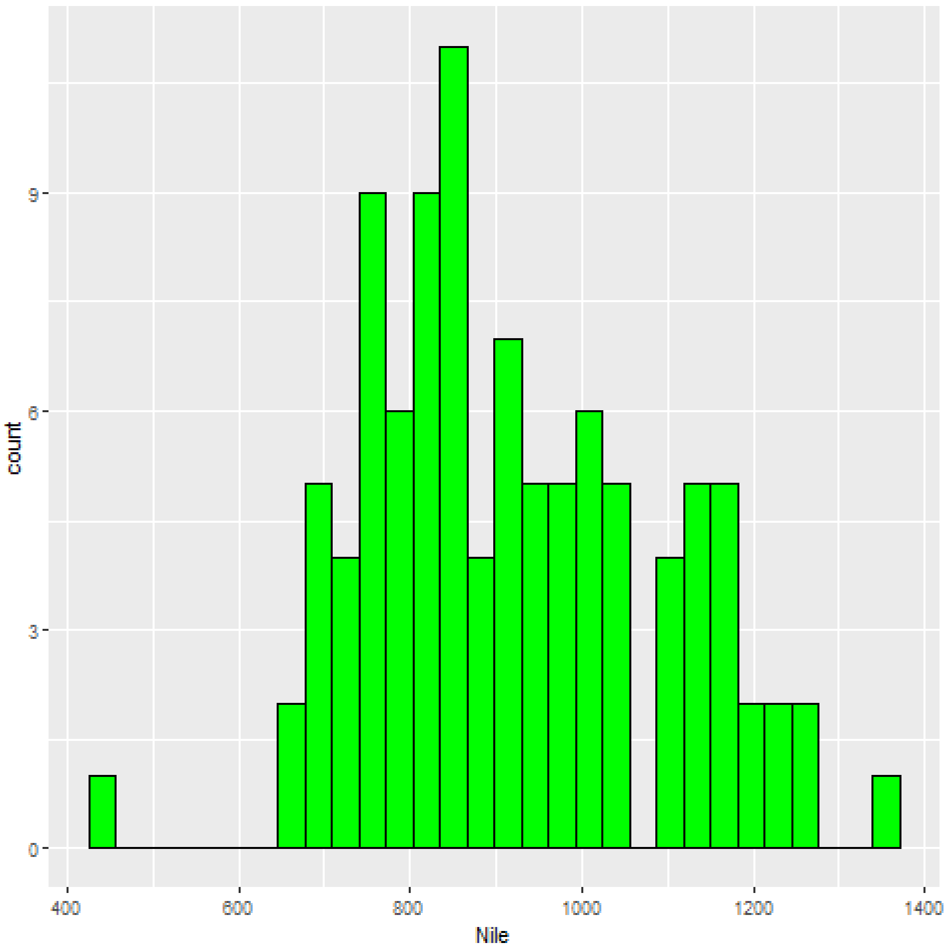
- Histogram of `mtcars$hp` in ggplot2:

```
library(ggplot2)
ggplot(data=mtcars,
       aes(x=hp)) +
  geom_histogram(binwidth=25, color="white", fill="red")
```

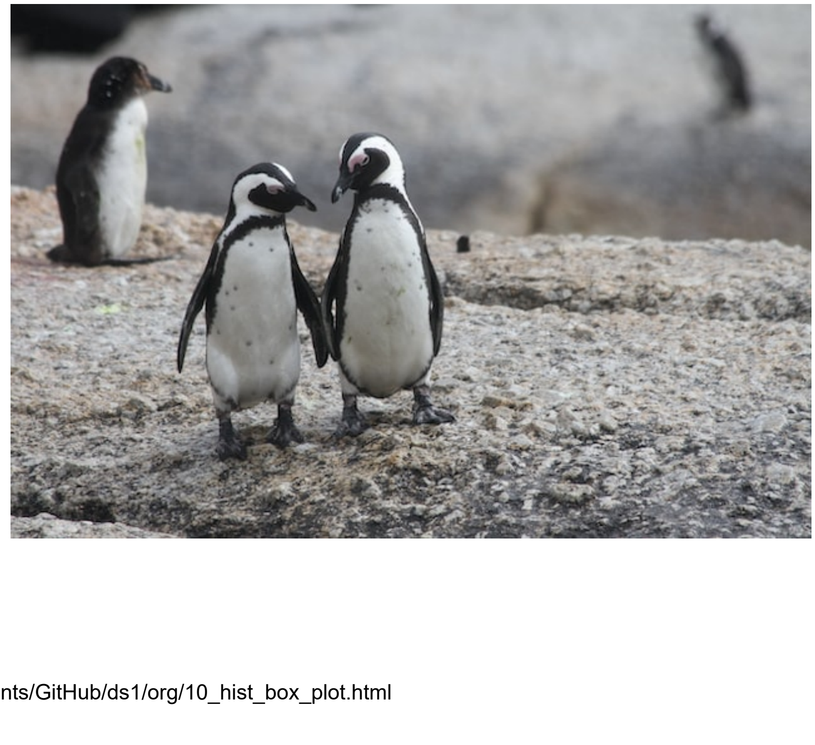


- A histogram of `Nile` is not so easy because it's a time series:

```
library(ggplot2)
ggplot(data=data.frame(Nile),
       aes(x=Nile)) +
  geom_histogram(color="black", fill="green")
```



4 Practice creating and customizing a histogram



- Download and open in GNU Emacs: tinyurl.com/nhkykkxr
- Work with a friend or with your neighbor in class
- Complete the problems in the file (we'll discuss at the end)
- Upload the result (for each participants) to Canvas (Practice 10)

5 Boxplots - global summary stats

- Open the practice file in Emacs to code along: tinyurl.com/2e6dy9yb
- Box-and-whisker plots, or boxplots represent the five-number `summary`:
  1. Minimum
  2. 1st quartile (25% of the values are below it)
  3. Median (50% of the values are below/above it)
  4. Mean (Arithmetic average)
  5. 3rd quartile (75% of the values are below it)
  6. Maximum

- For example for `x <- c(1,2,3,4,5,6,7,8,9,10)`:

```
x <- c(1:10
summary(x)
```

```
Error: unexpected symbol in:
"x <- c(1:10
summary"
```

- For the built-in `quakes` data frame of 1,000 seismic events near the island of Fiji (depth, magnitude, number of observing stations):

```
summary(quakes[,c("depth","mag","stations")])
```

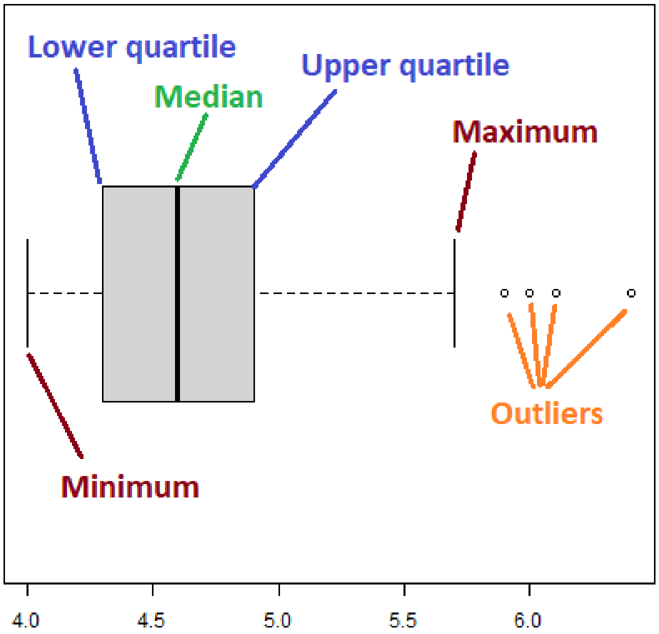
```
    depth            mag          stations
Min.   : 40.0   Min.   :4.00   Min.   : 10.00
1st Qu.: 99.0   1st Qu.:4.30   1st Qu.: 18.00
Median :247.0   Median :4.60   Median : 27.00
Mean   :311.4   Mean   :4.62   Mean   : 33.42
3rd Qu.:543.0   3rd Qu.:4.90   3rd Qu.: 42.00
Max.   :680.0   Max.   :6.40   Max.   :132.00
```

- Each record/row represents one recorded earthquake: where it was located, at which depth the epicenter was, its magnitude, and the number or observing stations:

```
head(quakes)
```

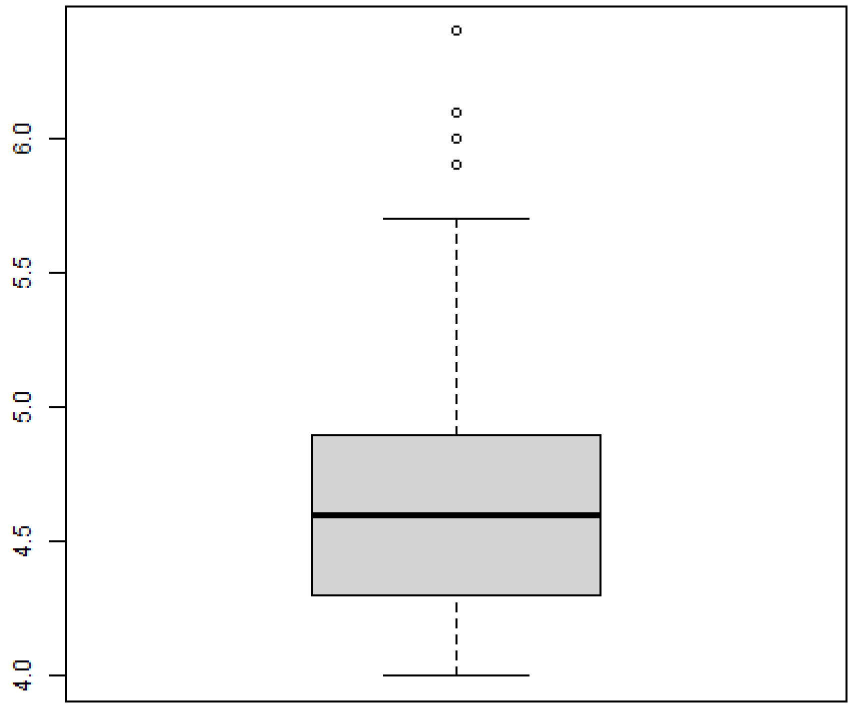
```
     lat   long depth mag stations
1 -20.42 181.62   562 4.8       41
2 -20.62 181.03   650 4.2       15
3 -26.00 184.10    42 5.4       43
4 -17.97 181.66   626 4.1       19
5 -20.42 181.96   649 4.0       11
6 -19.68 184.31   195 4.0       12
```

- The boxplot of the earthquake magnitudes shows the output of `summary` except the `mean`, but it also shows *outliers*, extreme values that distort the mean:



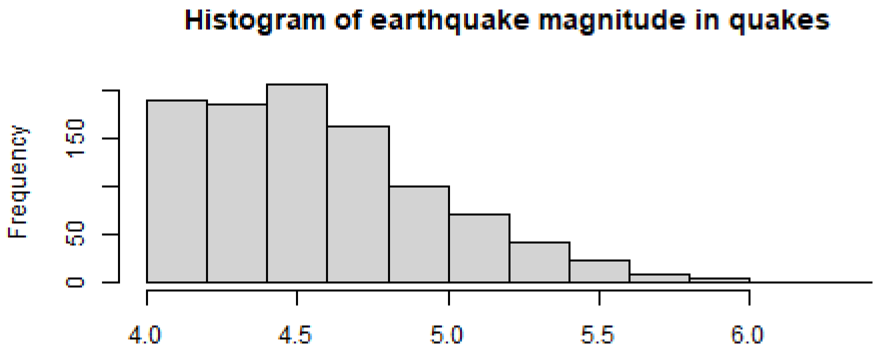
- Creating a boxplot is simple: for the earthquake magnitudes (`quakes$mag`):

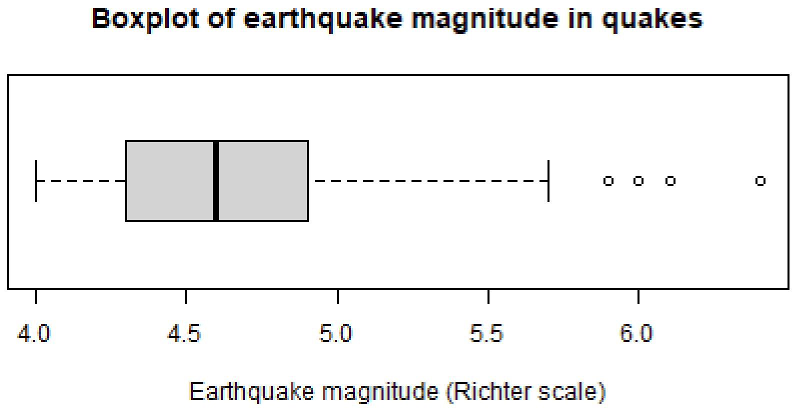
```
boxplot(quakes$mag)
```



- Let's look at histogram and boxplot on top of one another, with a minimal customization:

```
par(mfrow=c(2,1))
hist(quakes$mag, xlab="",
     main="Histogram of earthquake magnitude in quakes")
boxplot(quakes$mag,
        horizontal=TRUE,
        main="Boxplot of earthquake magnitude in quakes",
        xlab="Earthquake magnitude (Richter scale)")
```

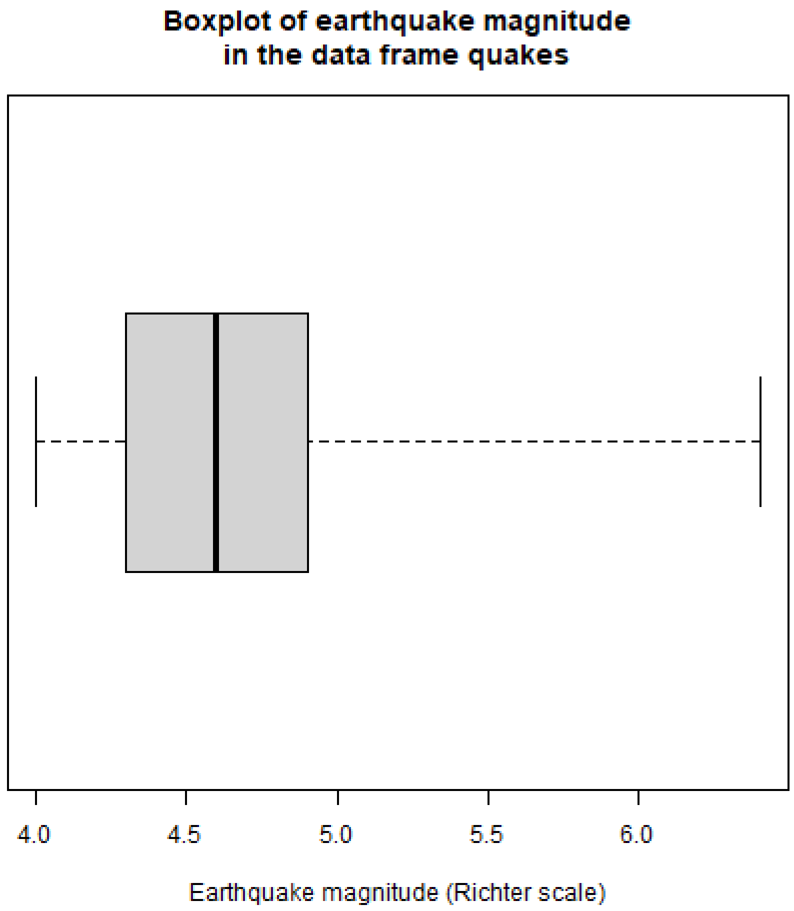




- Like the histogram, a boxplot shows important **global** (overall) features of the value distribution:
  - centrality (where is the midpoint of the distribution?)x
  - spread (how far are the whiskers apart, how wide is the box?)
  - skewness (where is the box relative to the whiskers?)
- The boxplot does not show important **local** features, like
  - modes (multiple significant peaks or maxima)
  - valleys (local minima)
- Outliers are displayed explicitly (computed as 1.5 times the Inter-Quartile Range or IQR)

- The `range` parameter in `boxplot` determines how far the whiskers should extend from the box. `range=0` includes all values.

```
boxplot(quakes$mag, horizontal=TRUE,
        range=0,
        main="Boxplot of earthquake magnitude\nin the data frame quakes",
        xlab="Earthquake magnitude (Richter scale)")
```



6 Side-by-side boxplots

- Boxplots are useful to compare data features by plotting them side-by-side, e.g. for identifying how many monitoring stations detected each event

- We use `cut` to create three levels of stations for three boxes:

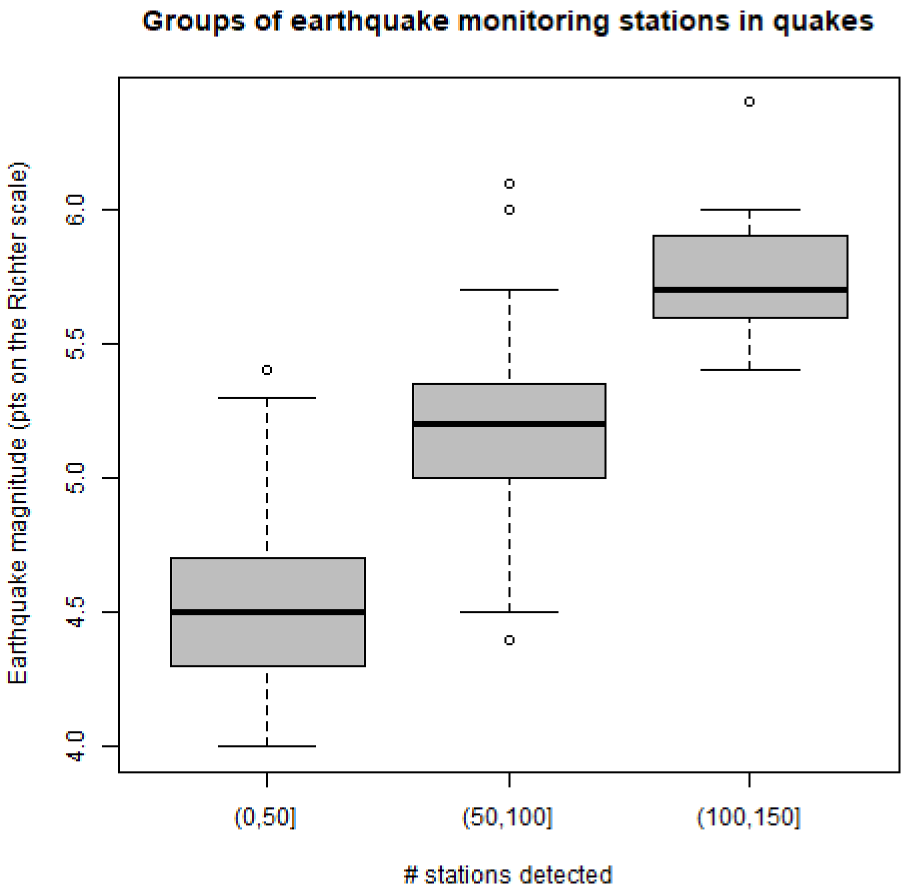
```
stations <- cut(quakes$stations, breaks=c(0,50,100,150))
stations[1:5] # first five elements
```

```
[1] (0,50] (0,50] (0,50] (0,50] (0,50]
Levels: (0,50] (50,100] (100,150]
```

- The factor `stations` breaks the observations in three groups
  1. events detected by 50 stations or fewer `(0,50]`
  2. events detected by 51 to 100 stations `(50,100]`
  3. events detected by between 100 and 150 stations `(100,150]`

- The boxplot compares the distributions of the magnitudes of the events according to these three groups:

```
boxplot(quakes$mag ~ stations,
        main="Groups of earthquake monitoring stations in quakes",
        xlab="# stations detected",
        ylab="Earthquake magnitude (pts on the Richter scale)",
        col="gray")
```



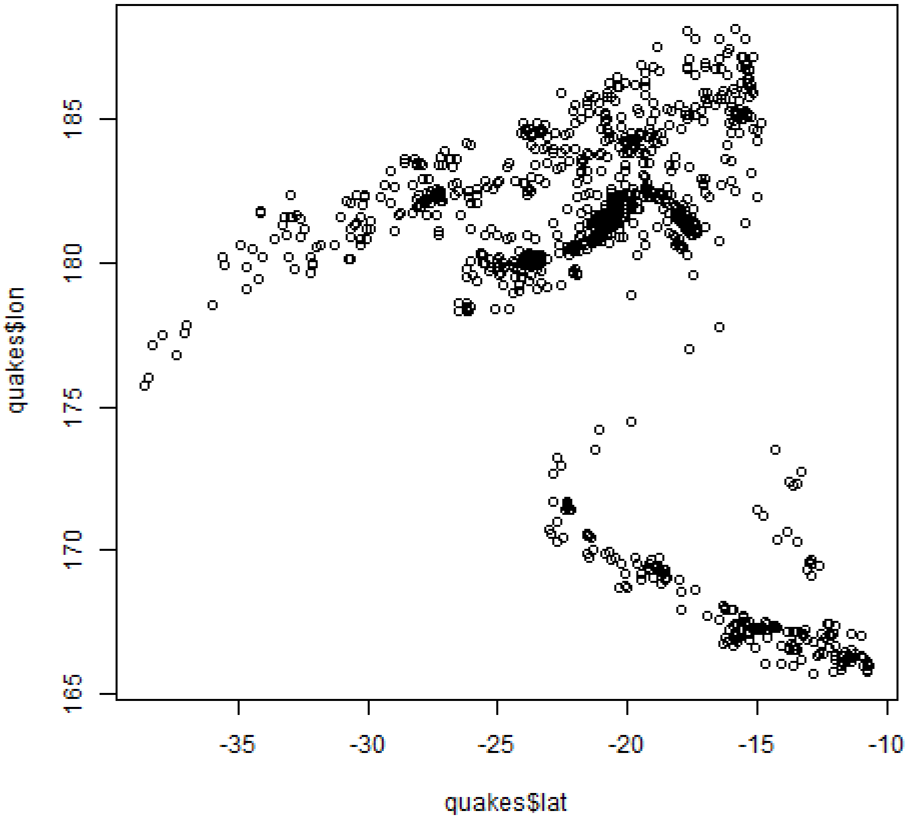
- You can see that the higher the recorded magnitude, the more stations detected the given seismic event
- In the argument, we've used the *formula* `y ~ x` ("y vs. x") with `x=stations` and `y=quakes$mag`. If the `y ~` is missing, the argument is taken as `x` (cp. `help(boxplot)`).

7 Scatterplots

- Scatterplots are used to identify relationships between the observed values of two different numeric-continuous variables x,y

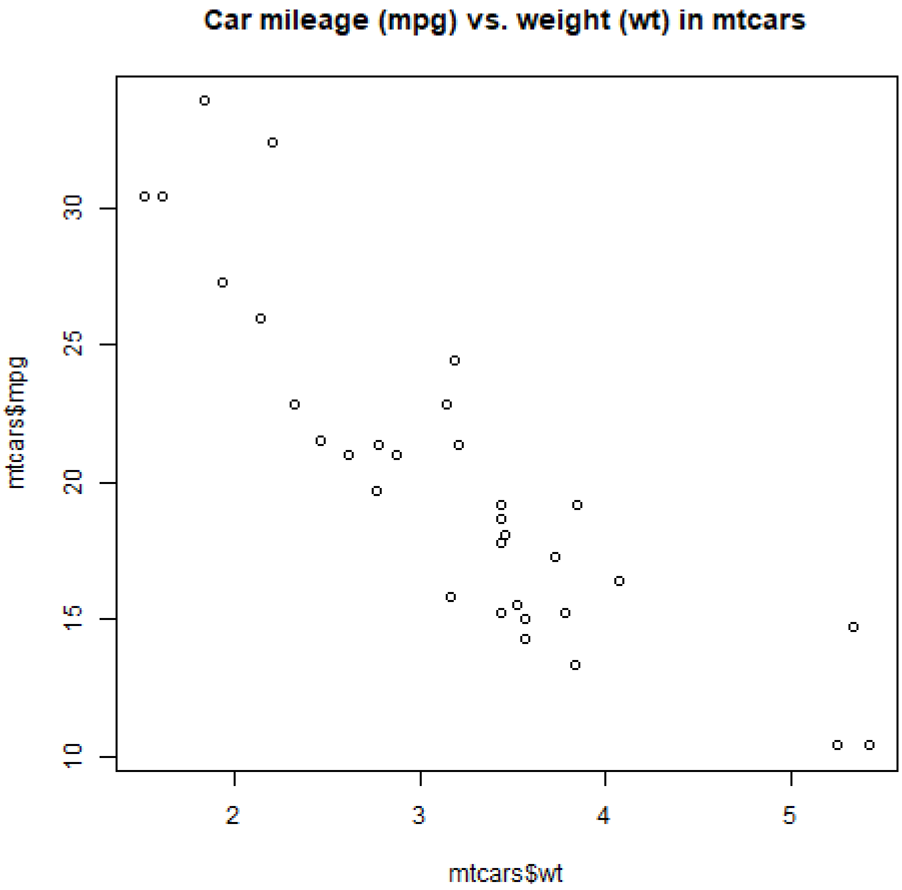
- The scatterplot is displayed as an x-y-coordinate plot but not every x-y-plot shows relationships of interest - e.g. a plot of the latitude vs. longitude in `quakes`:

```
plot(x=quakes$lat,
     y=quakes$lon)
```



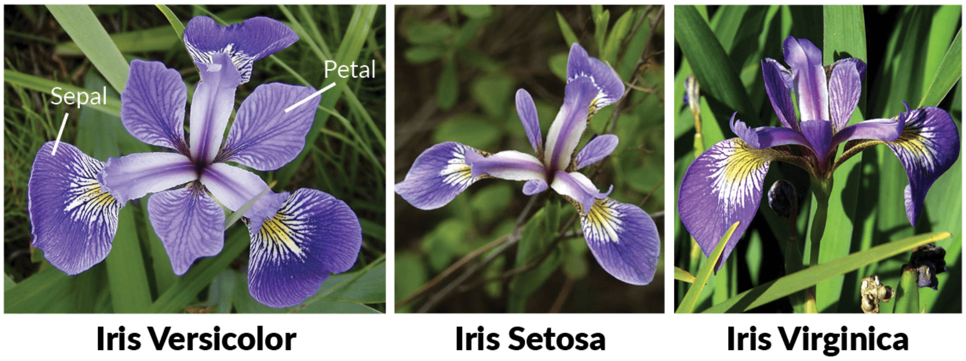
- A real scatterplot is the visualization of the mileage (`mpg`) vs. weight (`wt`) of cars in the built-in `mtcars` data set:

```
plot(mtcars$mpg ~ mtcars$wt)
title("Car mileage (mpg) vs. weight (wt) in mtcars")
```



8 Scatterplots of more than two variables

- The famous `iris` dataset, collected in the mid-1930s, contains petal and sepal measurements for three species of perennial iris flowers, *Iris setosa*, *Iris virginica*, and *Iris versicolor* (Fisher, 1936).



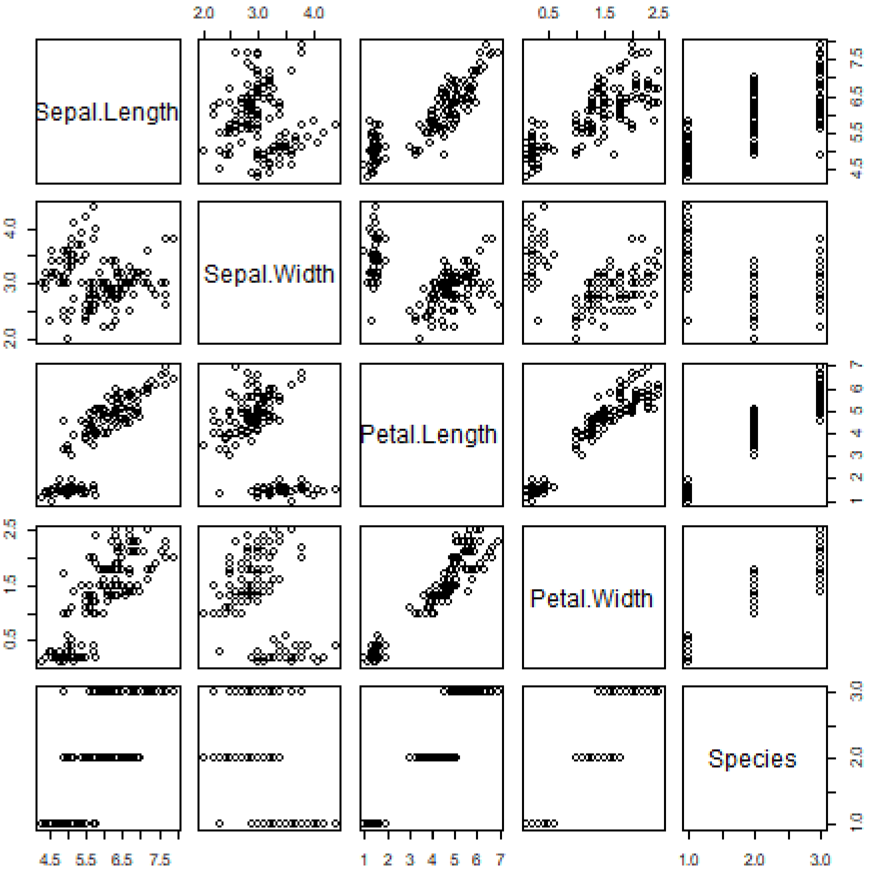
- View the first few records:

```
head(iris[1:5])
```

```
  Sepal.Length Sepal.Width Petal.Length Petal.Width Species
1          5.1         3.5          1.4         0.2  setosa
2          4.9         3.0          1.4         0.2  setosa
3          4.7         3.2          1.3         0.2  setosa
4          4.6         3.1          1.5         0.2  setosa
5          5.0         3.6          1.4         0.2  setosa
6          5.4         3.9          1.7         0.4  setosa
```

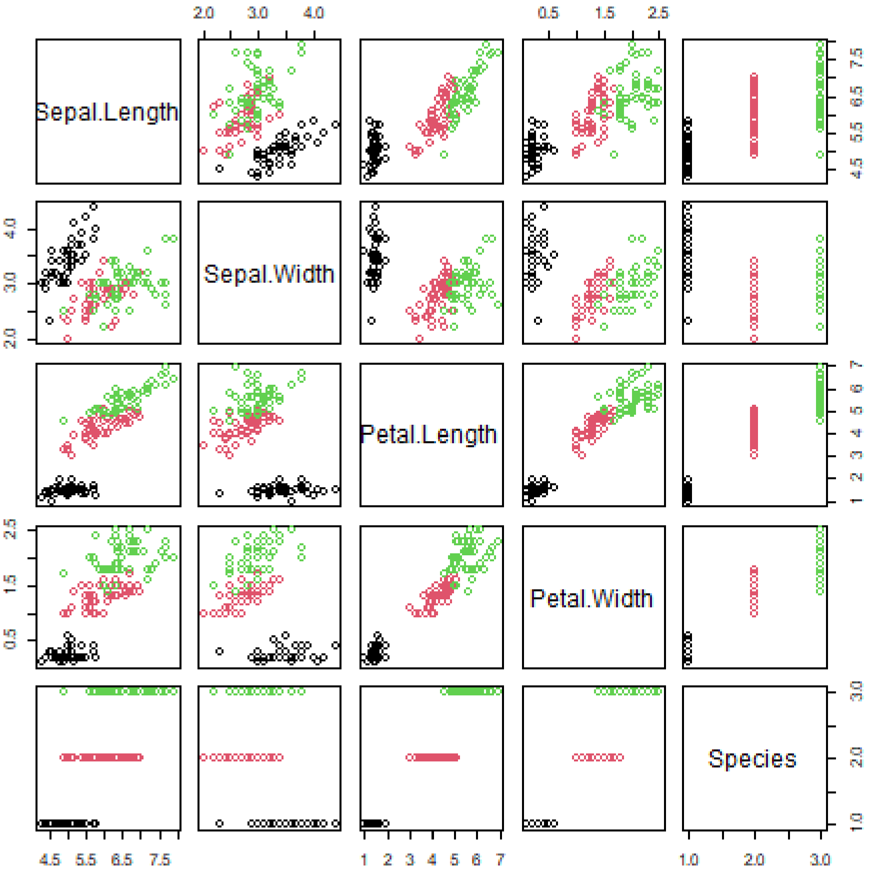
- To plot every variable against every other, you can plot an array of x-y-plots:
  - Each column has the shown variable as x- and the others as y-axis
  - Each row has the shown variable as y- and the others as x-axis
  - E.g. the square (2,1) shows x = `Sepal.Length`, y = all others

```
plot(iris)
```



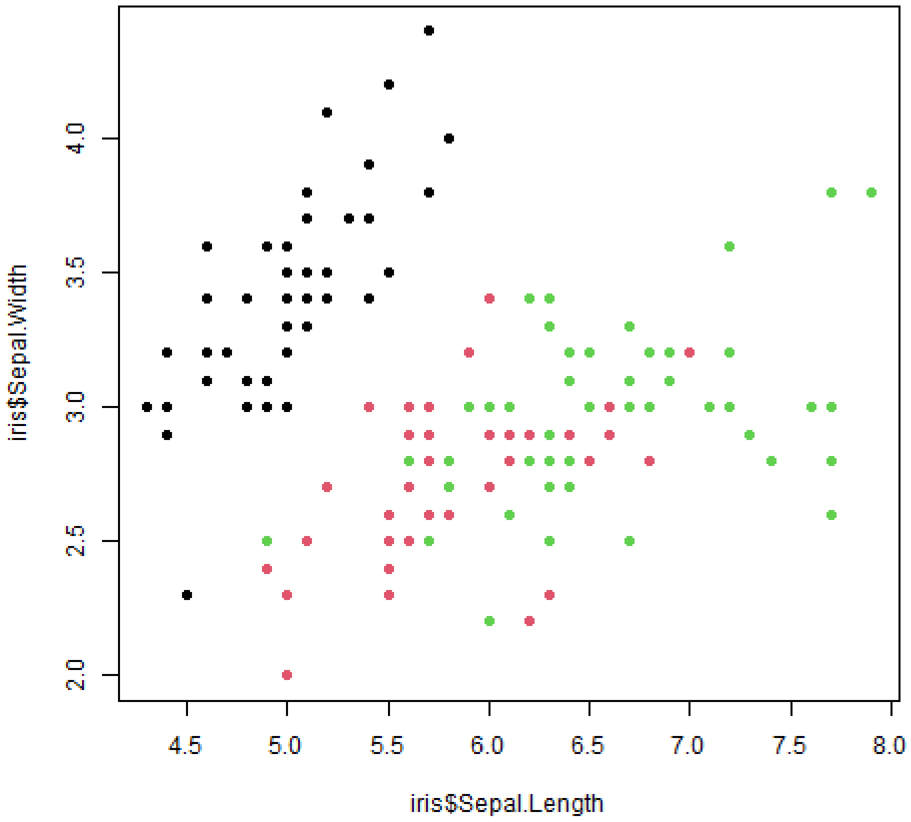
- The array is much easier to read when adding the iris species as a sixth variable to the plot.

```
plot(iris, col=iris$Species)
```



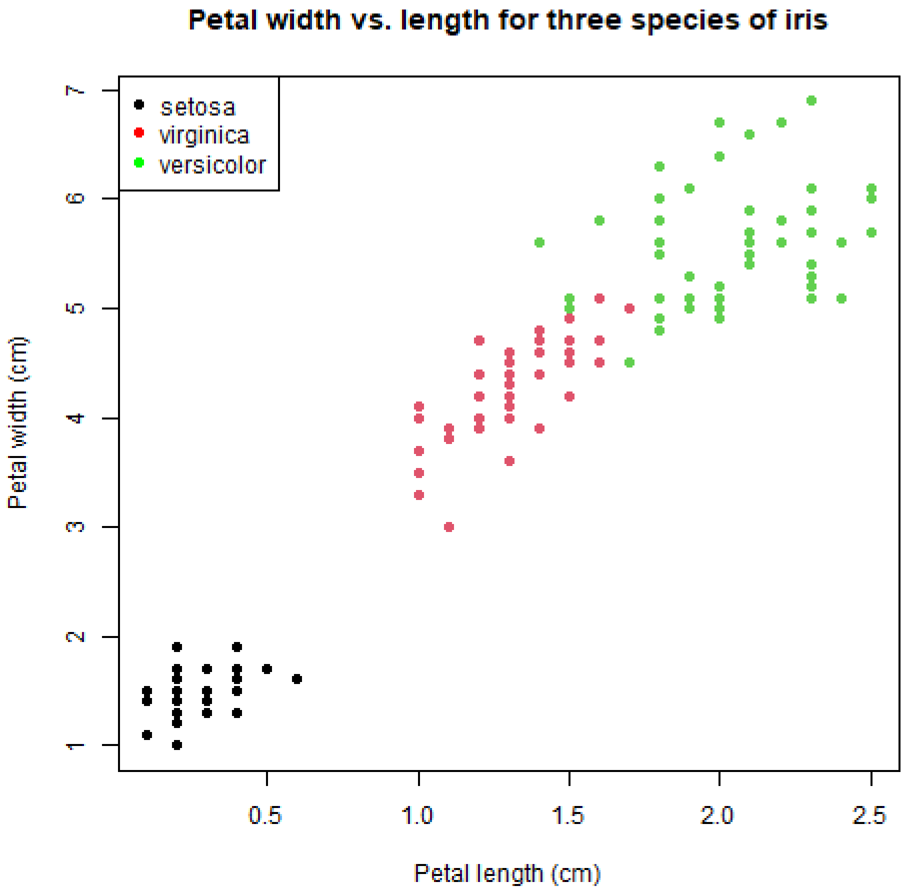
- Homing in on one of the diagrams, e.g. `Sepal.Width` vs. `Sepal.Length`:

```
plot(
  iris$Sepal.Width ~ iris$Sepal.Length,
  col=iris$Species,
  pch=19)
```



- As an example for a fully customized plot with legend:

```
plot(
  y=iris$Petal.Length, xlab="Petal length (cm)",
  x=iris$Petal.Width, ylab="Petal width (cm)",
  col=iris$Species,
  pch=19)
legend("topleft",
       legend=c("setosa", "virginica","versicolor"),
       col=c("black","red","green"), pch=19)
title("Petal width vs. length for three species of iris")
```



9 References

- "ggplot2 barplots: Quick start guide", sthda.com

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