Basic plotting in R - barplots and pie charts

Introduction to data science (DSC 105) Fall 2022

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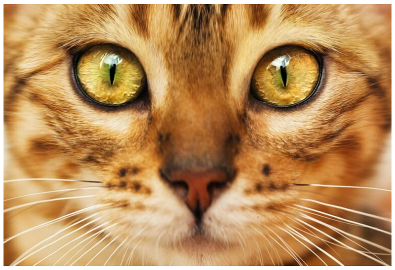
1 What's in it for you?



- Why visualization? What does it depend on?
- What types of charts are there?
- Barplots and pie charts
- Histograms
- Box-and-Whisker Plots
- Scatterplots

- Using base R and ggplot2

  Source: Davies (2016), chapter 14, pp. 289-308.

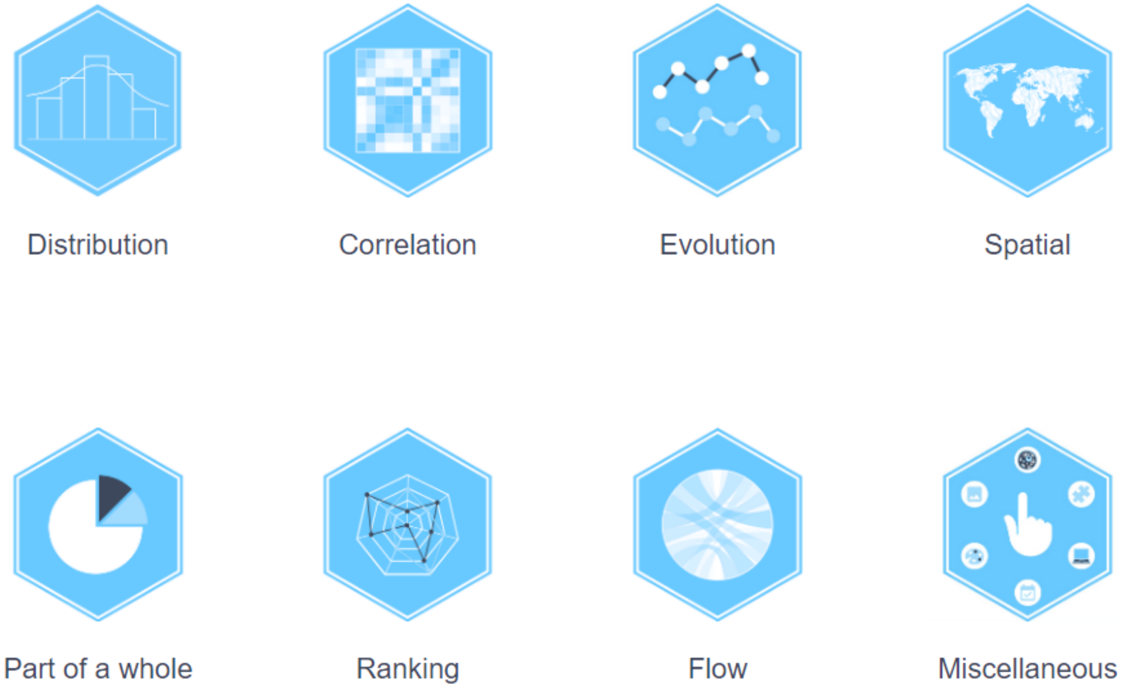
2 When do we visualize data? When don't we?

Data visualization is important for EXPLORATION and for DOCUMENTATION:

1. During data **exploration** (EDA), we visualize to see **patterns** rather than rely on summary statistics and numbers only
2. During data **storytelling**, we document and communicate insights using graphs rather than tables (raw numbers)

It's easy to miss **relevant details** in graphs, and it's easy to miss the **big picture** in tables.

3 What does visualization depend on?



(Source: r-charts.com - base R and ggplot2 examples[1])

1. Raw/transformed data (observations and experiments)
2. Available/affordable tools (computing and infrastructure)
3. Variable types/style (related to the programming language)
4. Skill/Benefit (data scientists and data science customers)

4 About lists

- Lists should always be ordered by priority, and aligned by type.
- The poster suggests a priority: eating comes before praying comes before loving. Different people have different priorities!

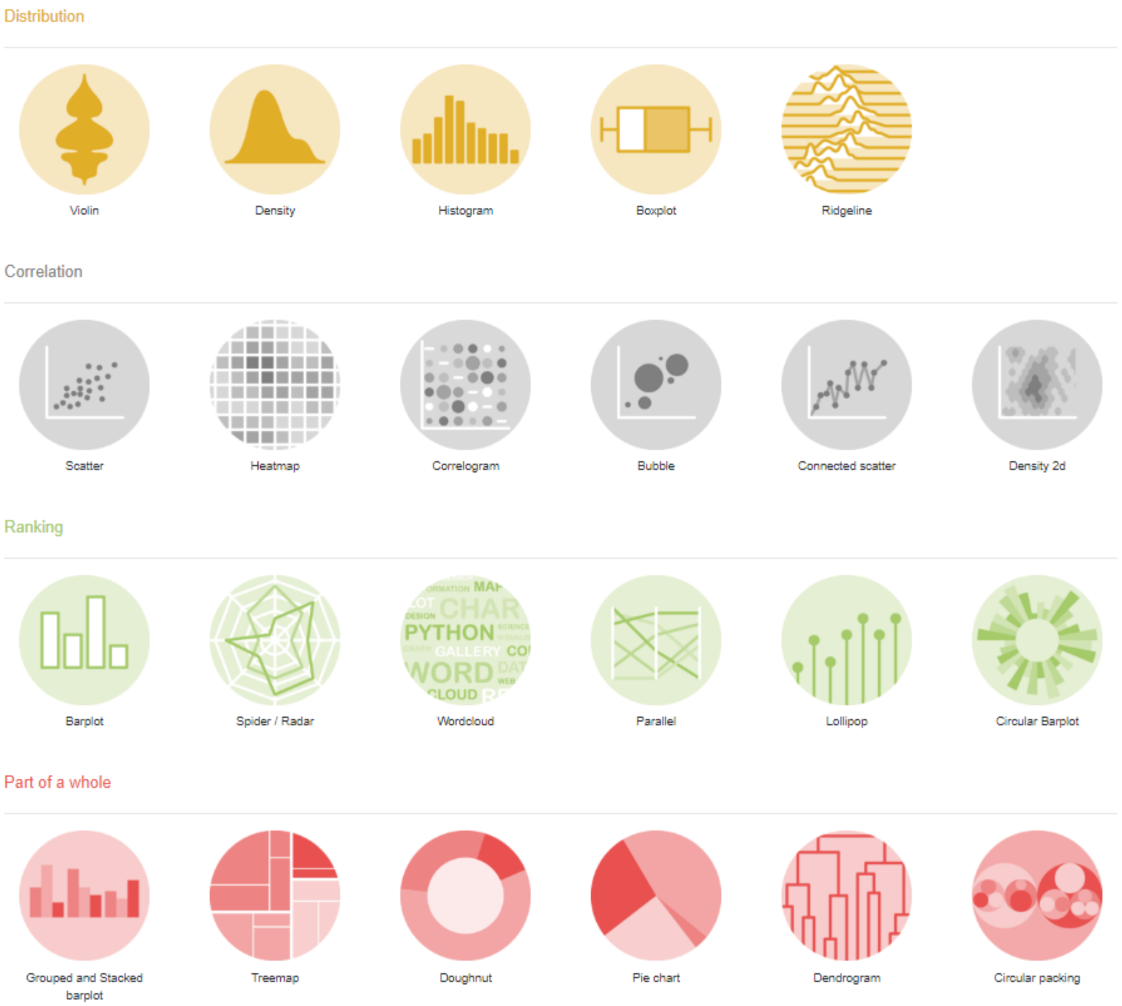
- The following example fails on both categories: the priority order is a time order, and it is broken, and the list mixes nouns and verbs:

    1. Going home
    2. Go to sleep
    3. Supper

- Better:

    1. Going home
    2. Eating supper
    3. Going to sleep

5 What types of visualizations are there?

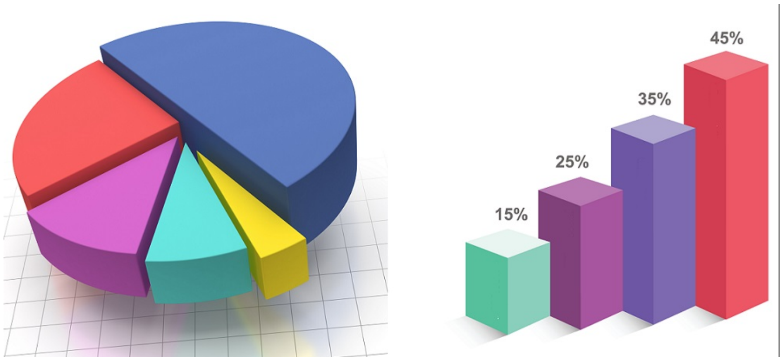


(Source: r-graph-gallery.com)

- Plots with bars (bar plot, histogram, lollipop, dotplot, pie chart)
- Plots with curves (density, ridgeline)
- Plots with points (scatterplot, bubbleplot, correlogram, line plot)

- Plots with areas (mosaicplot, boxplot, violinplot)
- Plots with trees (treemap, dendrogram)

6 Barplots and Pie charts



- Barplots and pie charts are used to visualize **qualitative** data by **category frequency**
- The height of the bars of a **barplot** indicate the frequency or count of each category
- The size of the segment of the **pie chart** indicate the frequency or count of each category

7 Frequency tables

- Frequencies can be computed using the `table` function

- Example: look at the dataset `ToothGrowth` - it has two `numeric` and one `factor` variable.

```
str(ToothGrowth)
tg <- ToothGrowth
```

```
'data.frame':	60 obs. of  3 variables:
 $ len : num  4.2 11.5 7.3 5.8 6.4 10 11.2 11.2 5.2 7 ...
 $ supp: Factor w/ 2 levels "OJ","VC": 2 2 2 2 2 2 2 2 2 2 ...
 $ dose: num  0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 0.5 ...
```

- Compute the frequencies for the variables of `ToothGrowth`

```
table(tg$len)
table(tg$supp)
table(tg$dose)
```

```

 4.2  5.2  5.8  6.4    7  7.3  8.2  9.4  9.7   10 11.2 11.5 13.6 14.5 15.2 15.5
   1    1    1    1    1    1    1    1    2    2    2    1    1    3    2    1
16.5 17.3 17.6 18.5 18.8 19.7   20 21.2 21.5 22.4 22.5   23 23.3 23.6 24.5 24.8
   3    2    1    1    1    1    1    1    2    1    1    1    2    2    1    1
25.2 25.5 25.8 26.4 26.7 27.3 29.4 29.5 30.9 32.5 33.9
   1    2    1    4    1    2    1    1    1    1    1

OJ VC
```

```
30 30

0.5   1   2
 20  20  20
```

- What do these results mean? Which questions does each `table` result answer?

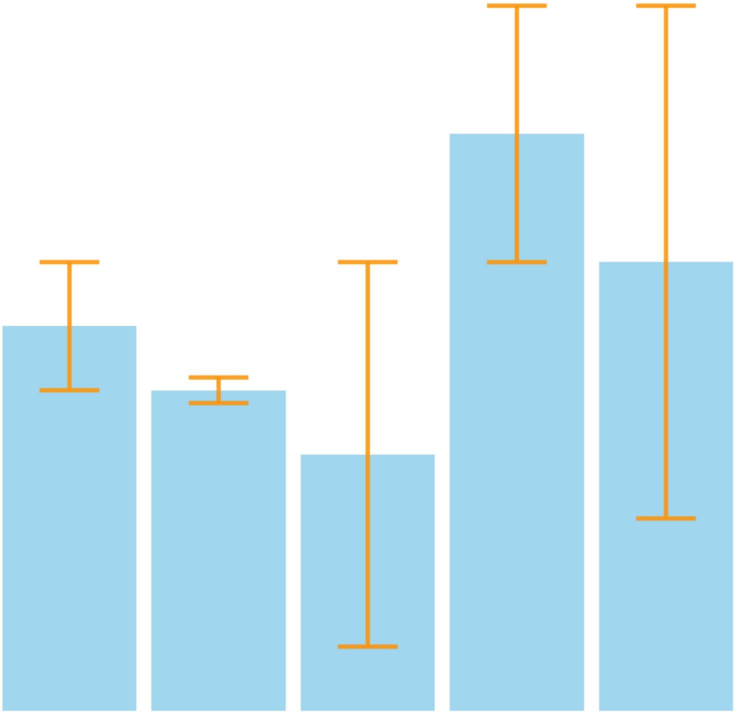
  > How many observations correspond to the values of `len`, `supp` and `dose`?

- What kind of R data structure is this frequency table? What structure does a table have? Is the table named or unnamed?

```
tbl <- table(ToothGrowth$supp)
class(tbl)
str(tbl)
names(tbl)
```

```
[1] "table"
 'table' int [1:2(1d)] 30 30
 - attr(*, "dimnames")=List of 1
  ..$ : chr [1:2] "OJ" "VC"
[1] "OJ" "VC"
```

8 How to build a barplot



- A barplot draws vertical or horizontal bars separated by white space, to visualize frequencies according to the relevant categories

- You can visualize raw quantities (i.e. counts), or functions of them, like the `mean` or proportions
- For more than one variable, the bars can be stacked or dodged (drawn next to one another)
- Example: to build barplots for any variable, we merely pass the frequency table to the `barplot` function. The value of each table entry determines the height of the bar: `barplot(table(var))`

9 Building a barplot for `mtcars`

- As an example let's use `mtcars`, which contains characteristics of 32 classic performance cars in the mid-1970s.

- Print the first 5 rows of the data frame `mtcars`

```
head(mtcars,5)
```

```
                   mpg cyl disp  hp drat    wt  qsec vs am gear carb
Mazda RX4         21.0   6  160 110 3.90 2.620 16.46  0  1    4    4
Mazda RX4 Wag     21.0   6  160 110 3.90 2.875 17.02  0  1    4    4
Datsun 710        22.8   4  108  93 3.85 2.320 18.61  1  1    4    1
Hornet 4 Drive    21.4   6  258 110 3.08 3.215 19.44  1  0    3    1
Hornet Sportabout 18.7   8  360 175 3.15 3.440 17.02  0  0    3    2
```

- We're only interested in one variable, `cyl`, the number of cylinders of the cars listed.

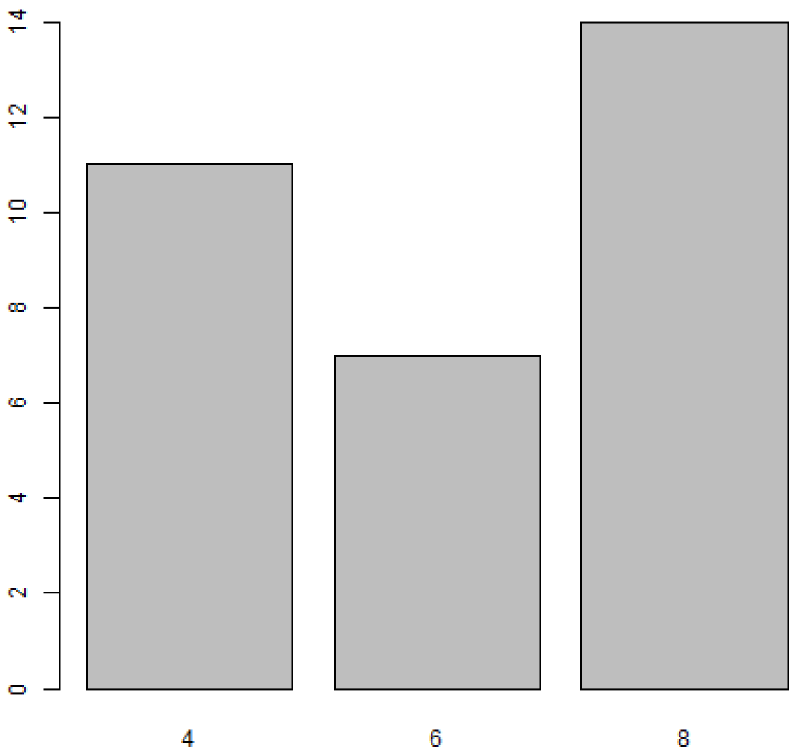
- We use `table` to find out how many cars have how many cylinders and store the result in `cyl.freq`

```
cyl.freq <- table(mtcars$cyl)
cyl.freq
```

```

 4  6  8
11  7 14
```

- We create a barplot of the cylinder frequencies in `mtcar`

```
barplot(cyl.freq)
```



- The plot displays the number of 4-, 6- and 8-cylinder cars in the data set but without annotations it's not clear what is summarized

10 Annotating a barplot

- Annotating a barplot works no different than annotating any plot, which is a great advantage of base R plotting

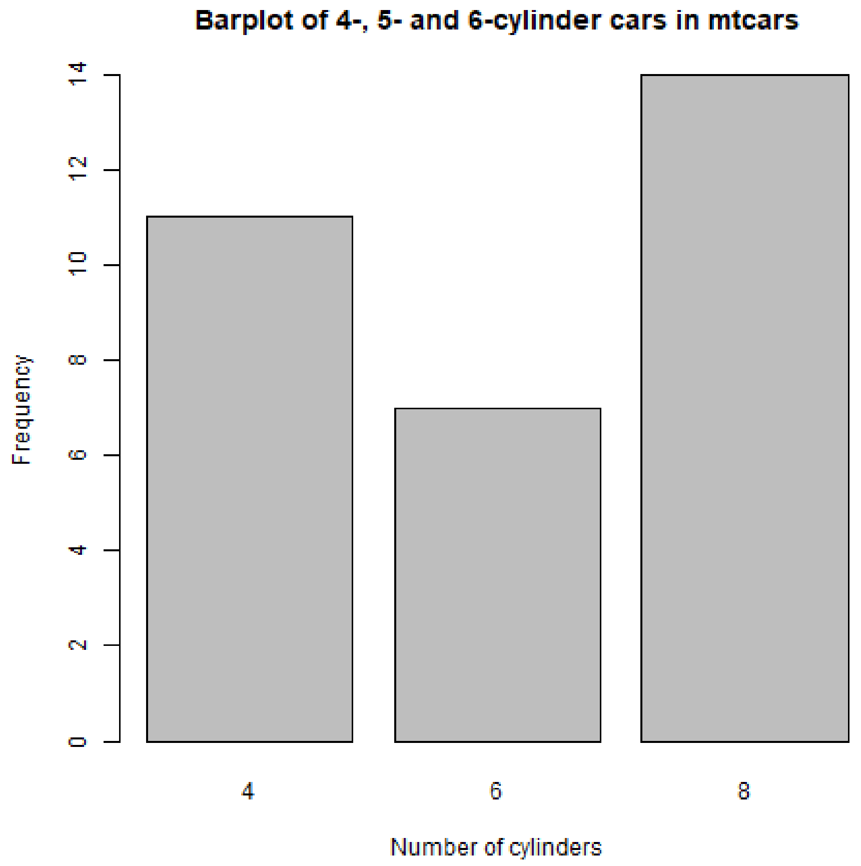
- The `barplot` function has a bunch of parameters, which you can view with `help` (if you run this in Org-mode, you have to quit with `C-g`)

```
#  help(barplot)
```

- For the simplest annotation, we need:
  1. title (`main`)
  2. x-axis label (`xlab`)
  3. y-axis label (`ylab`)

- Customization for the barplot of `cyl.freq`:

```
barplot(
  height = cyl.freq,
  main = "Barplot of 4-, 5- and 6-cylinder cars in mtcars",
  xlab = "Number of cylinders",
  ylab = "Frequency"
)
```



11 Practice: building a simple barplot

1. Check the `help` for the `read.csv` function. What's the difference between `read.csv` and `read.csv2`?

   The separator between the data is `,` for `read.csv` and `;` for `read.csv2`.

2. What is the meaning of the parameter `stringsAsFactors`?

   Setting this parameter to `TRUE` converts all `character` vectors to `factor` vectors.

3. Save the file at https://tinyurl.com/spdnvxbr as a data frame using `read.csv`. Look at the file to check if `header` should be `TRUE` or `FALSE`, and set `stringsAsFactors=TRUE`.

```
df <- read.csv(file="https://tinyurl.com/spdnvxbr",
               header=TRUE,
               stringsAsFactors=TRUE)
```

4. Save the file again as a data frame `dnf` but this time do **not** set `stringsAsFactors` to `TRUE`. Print the structure of `dnf`.

```
dnf <- read.csv(file="https://tinyurl.com/spdnvxbr",
                header=TRUE)
str(dnf)
```

```
'data.frame':   10 obs. of  4 variables:
 $ Weight: int  55 85 75 42 93 63 58 75 89 67
 $ Height: int  161 185 174 154 188 178 170 167 181 178
 $ Sex   : chr  "female" "male" "male" "female" ...
 $ Name  : chr  "Jane" "Jim" "Joe" "Carla" ...
```

1. Change the `character` vectors to `factor` vectors in `dnf`.

```
dnf$Sex <- factor(dnf$Sex)
dnf$Name <- factor(dnf$Name)
```

2. Use a function to check that `df` and `dnf` are identical.

```
identical(df,dnf)
```

```
[1] TRUE
```

3. Check the structure of the data frame `df`.

```
str(df)
```

```
'data.frame':   10 obs. of  4 variables:
 $ Weight: int  55 85 75 42 93 63 58 75 89 67
 $ Height: int  161 185 174 154 188 178 170 167 181 178
 $ Sex   : Factor w/ 2 levels "female","male": 1 2 2 1 2 2 1 2 2 1
 $ Name  : Factor w/ 10 levels "Carl","Carla",..: 7 8 9 2 1 3 6 4 5 10
```

4. Print the data frame.

```
df
```

```
   Weight Height    Sex  Name
1      55    161 female  Jane
2      85    185   male   Jim
3      75    174   male   Joe
4      42    154 female Carla
5      93    188   male  Carl
6      63    178   male Chris
7      58    170 female  Dora
8      75    167   male  Dave
9      89    181   male Derek
10     67    178 female Lucia
```

5. Compute the frequency table for the variable `Sex`, store it in `sex.freq` and print `sex.freq`.

```
sex.freq <- table(df$Sex)
sex.freq
```

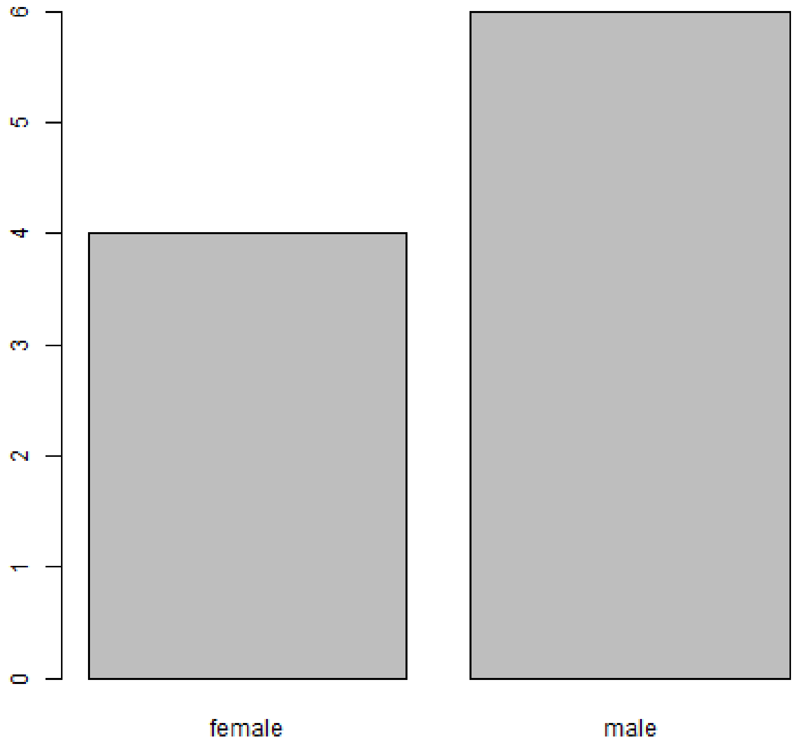
```

female   male
     4      6
```

6. What information does `sex.freq` contain? Write your answer below (as a full sentence).

   The data frame contains observations on four female and six male participants.

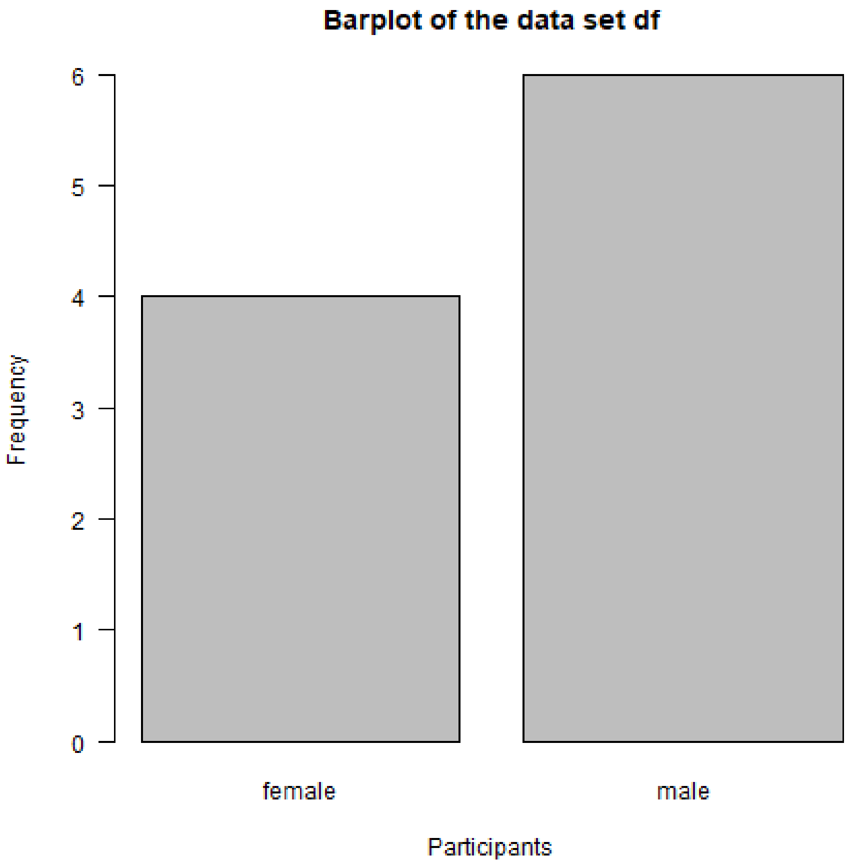
7. Create a barplot for the `Sex` category and store it in the file `sex.png`.

```
barplot(height = sex.freq)
```



8. Annotate the barplot by adding the title "Barplot of the data set df", and x- and y-axis labels. Orient the axis labels horizontally by adding the parameter `las=1`.

```
barplot(
  height = sex.freq,
  xlab = "Participants",
  ylab = "Frequency",
  main = "Barplot of the data set df",
  las = 1)
```



12 Building stacked/dodged barplots

- If you continue your exploration at this point in Org-mode, you can use `M-x org-babel-execute-buffer` to run all code blocks in this buffer

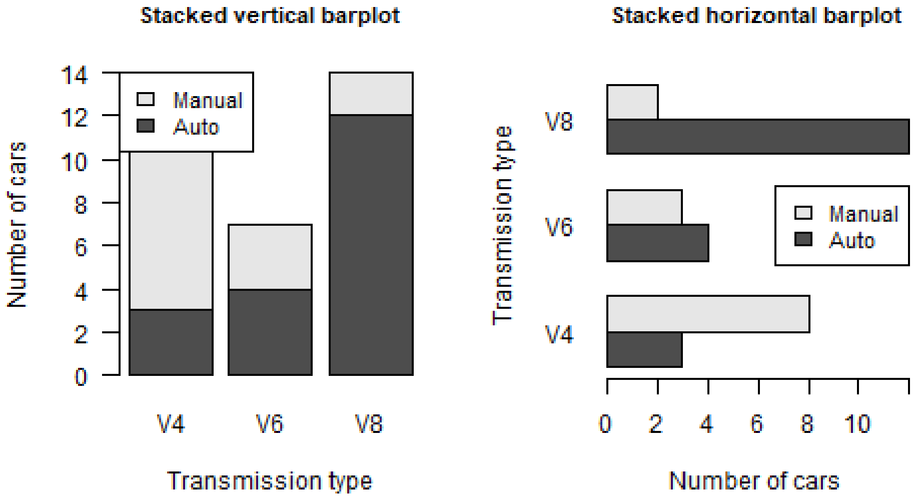
- We're interested in cylinder and transmission information from the `mtcars` data set: for example, how many 4-cylinder cars have automatic transmission?

```
cylinders <- mtcars$cyl
transmission <- mtcars$am

table(cylinders[transmission == 0])["4"]
```

```
4
3
```

- *Stacked* barplots have bars that are split up vertically

- In *dodged* or *side-by-side* barplots, the bars are broken up and placed next to one another - the figure shows the contrast:



13 Frequency matrix

- To make such plots, `barplot` needs a suitably arranged matrix as its first argument. E.g. for `cylinders` and `transmissions`, it shows the number of all cylinders associated with each transmission type:

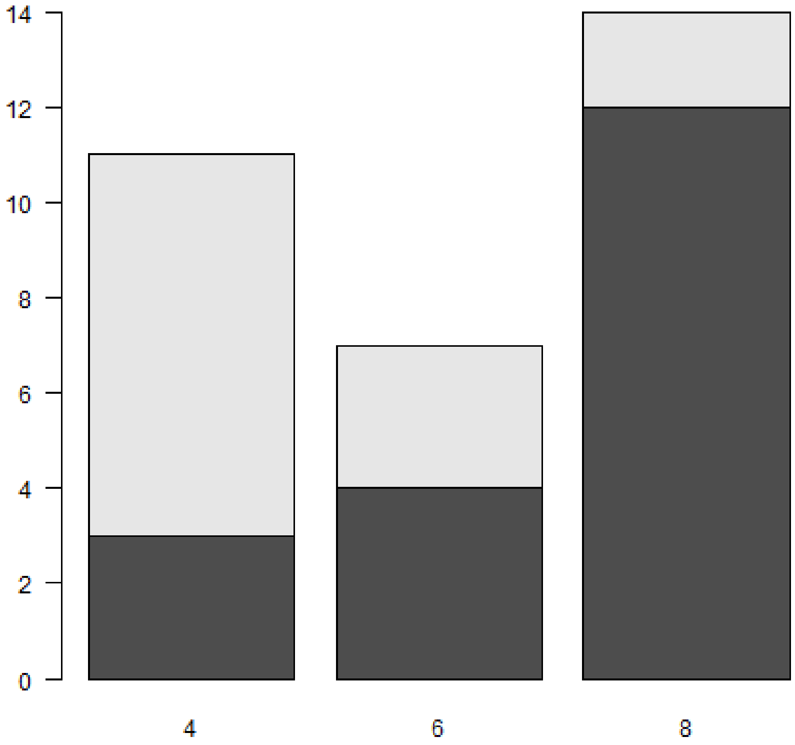
```
cyl.freq.matrix <- table(transmission, cylinders)
cyl.freq.matrix
```

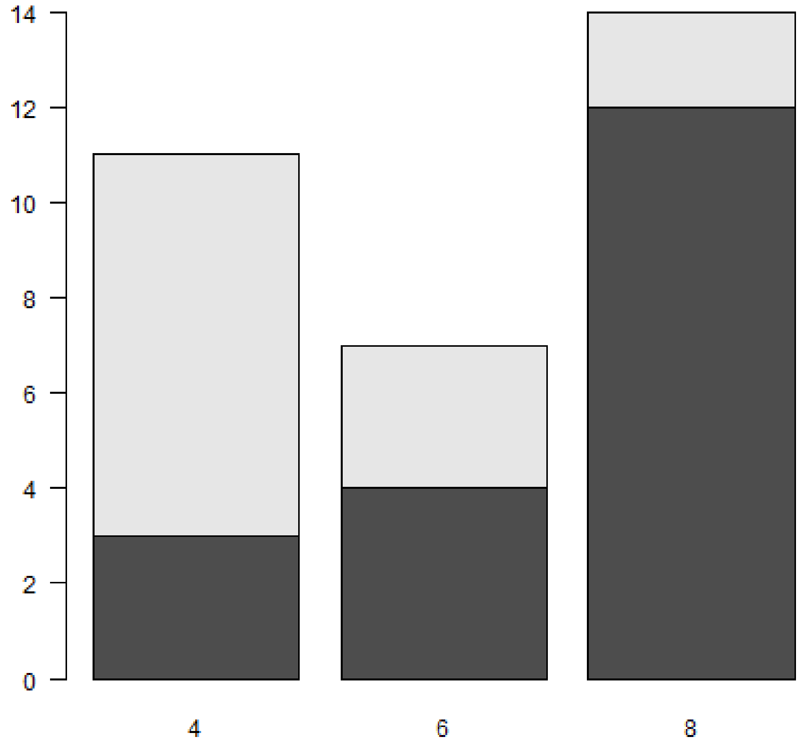
```
             cylinders
transmission  4  6  8
           0  3  4 12
           1  8  3  2
```

- The condition for `table` to cross-tabulate categorical variables (or vectors of discrete numeric values) is that the vectors have the **same length**.
- Column vectors having the same length means that for each observation, values of both variables were recorded: each car in `mtcars` has a `cylinders` and a `transmission` value.
- Each bar of the barplot corresponds to a column of the supplied matrix, and it is further split by the row values.

- Creating the barplot:

```
barplot(cyl.freq.matrix,
        las = 1)
```


14
12
10
8
6
4
2
0
4
6
8



- Each bar/column of the plot corresponds to a column of the categorical variable on the x-axis. Let's customize it!

14 Customizing barplots

- There are a LOT of potential parameters in `help(barplot)` with the default values.

```
barplot(height, width = 1, space = NULL,
        names.arg = NULL, legend.text = NULL, beside = FALSE,
        horiz = FALSE, density = NULL, angle = 45,
        col = NULL, border = par("fg"),
        main = NULL, sub = NULL, xlab = NULL, ylab = NULL,
        xlim = NULL, ylim = NULL, xpd = TRUE, log = "",
        axes = TRUE, axisnames = TRUE,
        cex.axis = par("cex.axis"), cex.names = par("cex.axis"),
        inside = TRUE, plot = TRUE, axis.lty = 0, offset = 0,
        add = FALSE, ann = !add && par("ann"),
        args.legend = NULL, ...)
```

- Let's look at some of these, which we will customize later:
  1. `height` is a non-optional argument (vector or matrix)
  2. `horiz = FALSE` means bars are drawn vertically (first on the left); if `TRUE`, bars are drawn horizontally (first at bottom)

3. `names.arg = NULL` means that names for each bar are taken from the `names` attribute of `height` if it is a vector, or the column names if it is a matrix (which is what happened here):

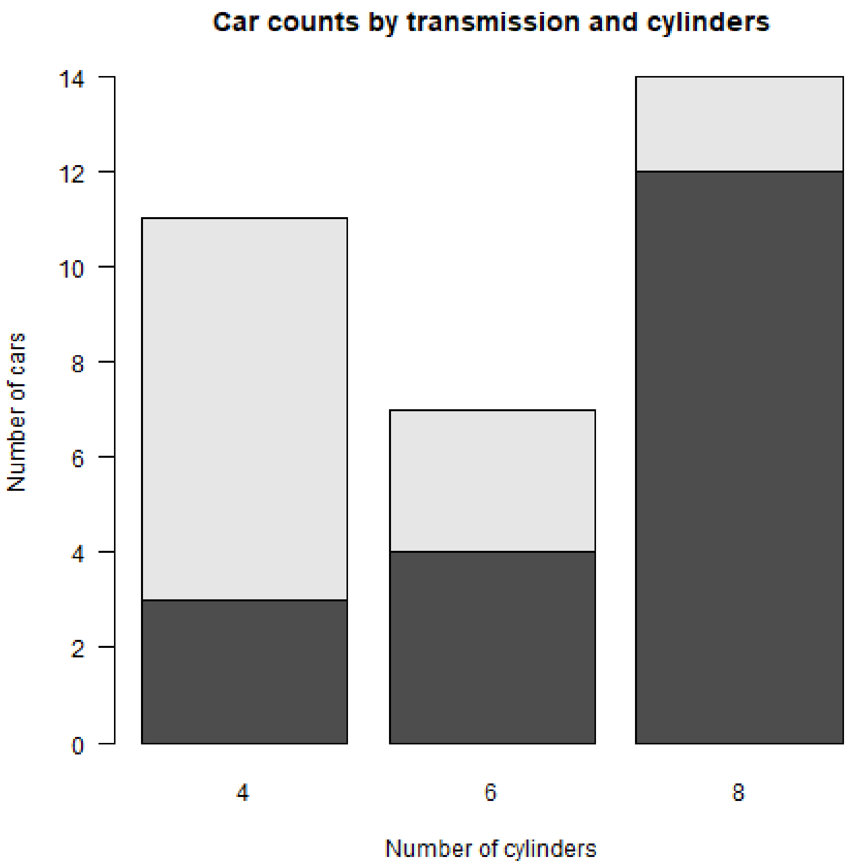
```
colnames(cyl.freq.matrix)
```

```
[1] "4" "6" "8"
```

4. `beside = FALSE` means stacked bars, `TRUE` means side-by-side bars
5. `legend.text` is a quick way to add a legend (always useful)

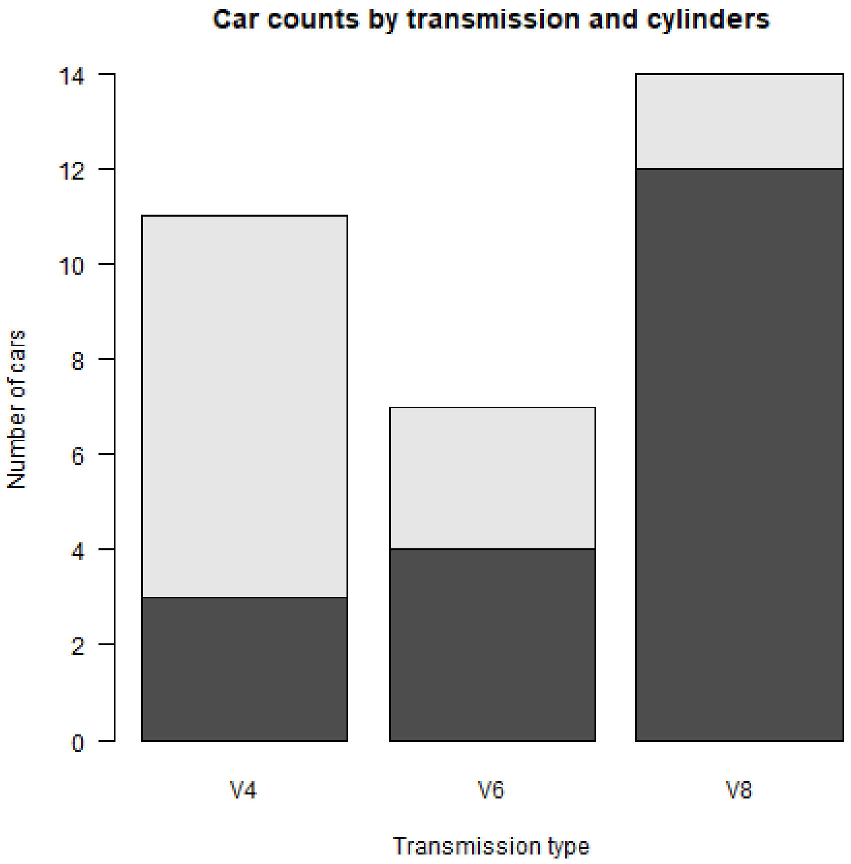
- We already know how to add a title and x- and y-axis labels:

```
barplot(cyl.freq.matrix,
        las = 1,
        main = "Car counts by transmission and cylinders",
        xlab = "Number of cylinders",
        ylab = "Number of cars")
```



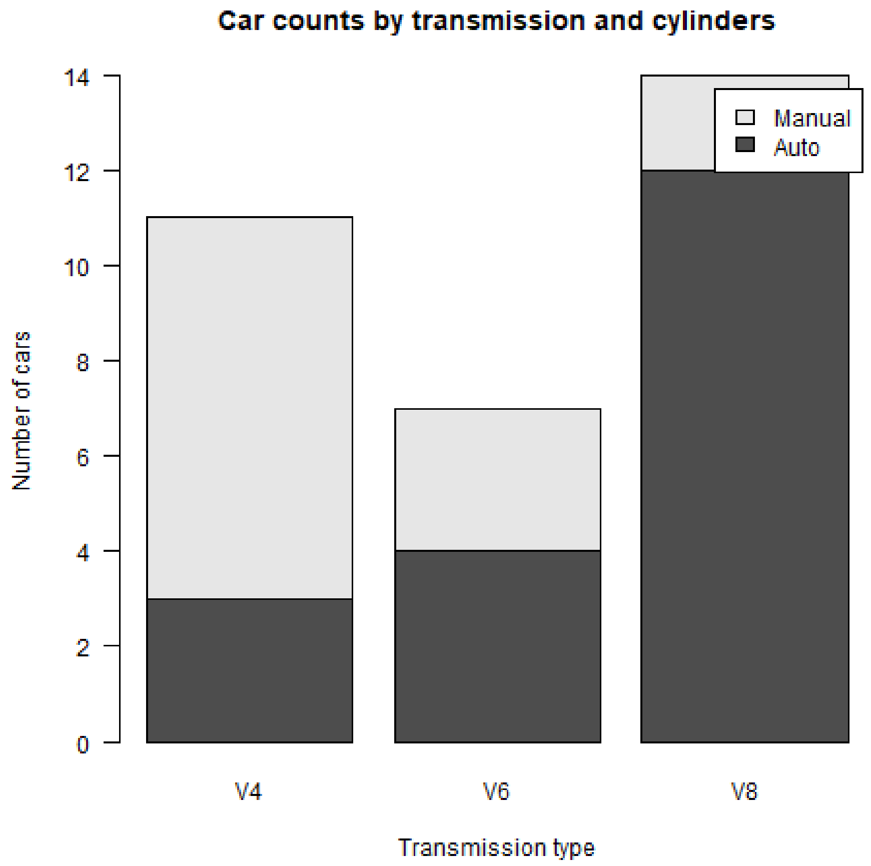
- Change the x-axis names to more meaningful values with `names.arg`:

```
barplot(cyl.freq.matrix,
        las = 1,
        main = "Car counts by transmission and cylinders",
        xlab = "Transmission type",
        ylab = "Number of cars",
        names.arg = c("V4", "V6", "V8"))
```



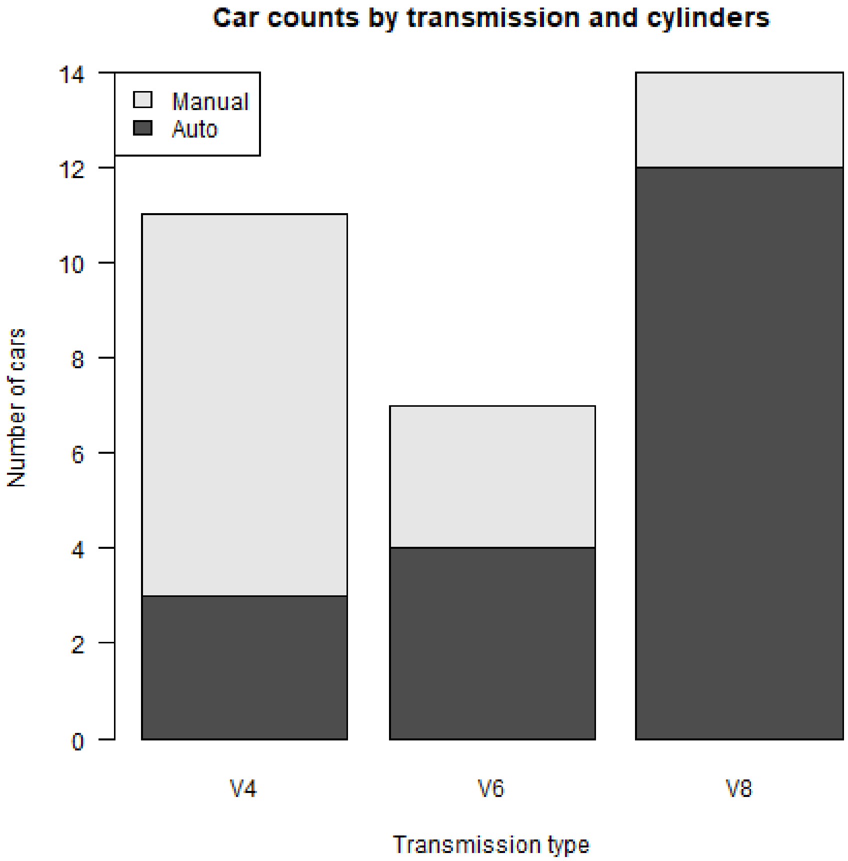
- Add a legend using `legend.text`:

```
barplot(cyl.freq.matrix,
        las = 1,
        main = "Car counts by transmission and cylinders",
        xlab = "Transmission type",
        ylab = "Number of cars",
        names.arg = c("V4", "V6", "V8"),
        legend.text = c("Auto", "Manual"))
```



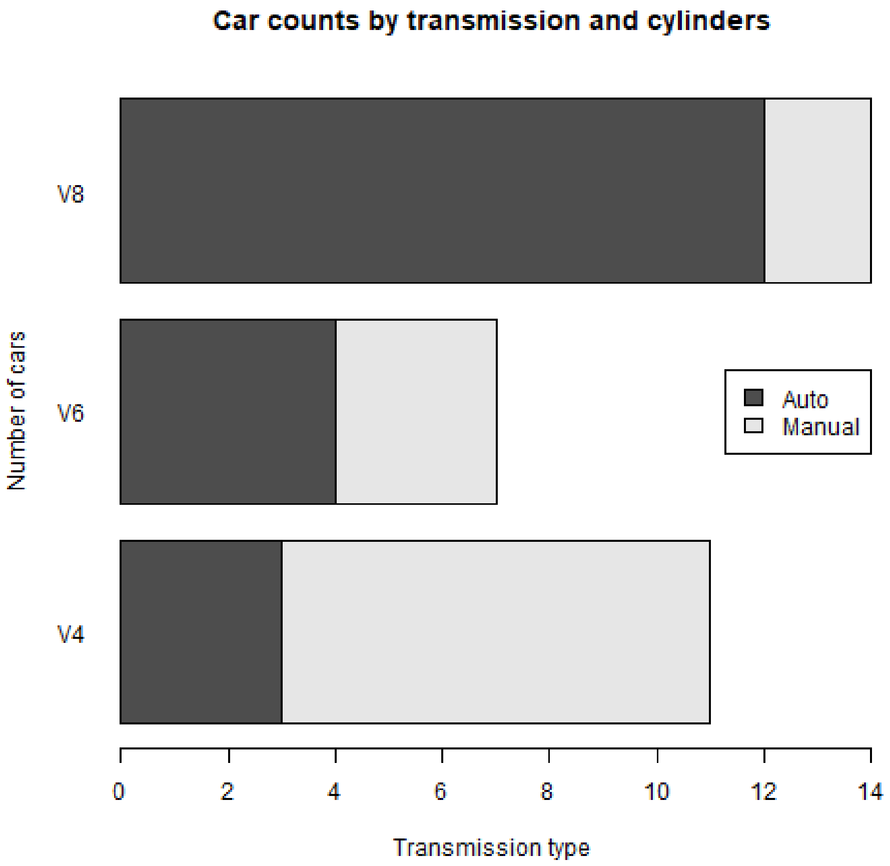
- We don't want the legend to overlap with the bars: we use the `args.legend` parameter to change the position:

```
barplot(cyl.freq.matrix,
        las = 1,
        main = "Car counts by transmission and cylinders",
        xlab = "Transmission type",
        ylab = "Number of cars",
        names.arg = c("V4", "V6", "V8"),
        legend.text = c("Auto", "Manual"),
        args.legend = list(x="topleft"))
```



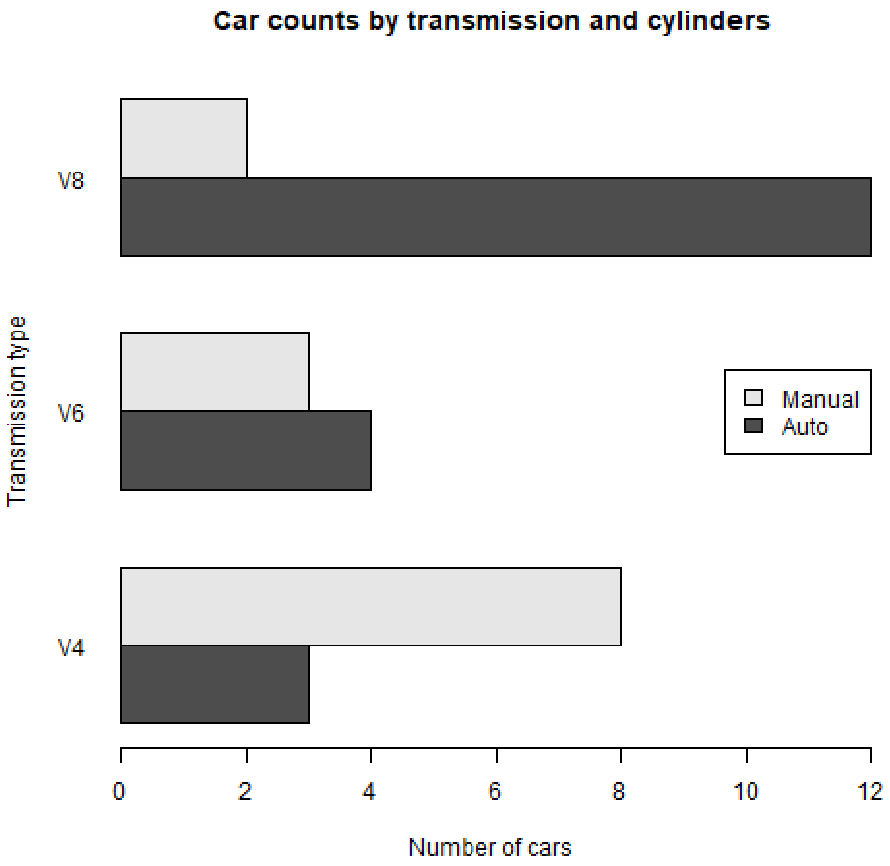
- Turning it on its side changing the parameter `horiz` to `TRUE` (and moving the legend to center `right`):

```
barplot(cyl.freq.matrix,
        las = 1,
        main = "Car counts by transmission and cylinders",
        xlab = "Transmission type",
        ylab = "Number of cars",
        names.arg = c("V4", "V6", "V8"),
        legend.text = c("Auto", "Manual"),
        args.legend = list(x="right"),
        horiz = TRUE)
```



- Finally, let's look at the dodged version of this plot:

```
barplot(cyl.freq.matrix,
        las = 1,
        main = "Car counts by transmission and cylinders",
        ylab = "Transmission type",
        xlab = "Number of cars",
        names.arg = c("V4", "V6", "V8"),
        legend.text = c("Auto", "Manual"),
        args.legend = list(x="right"),
        horiz = TRUE,
        beside = TRUE)
```

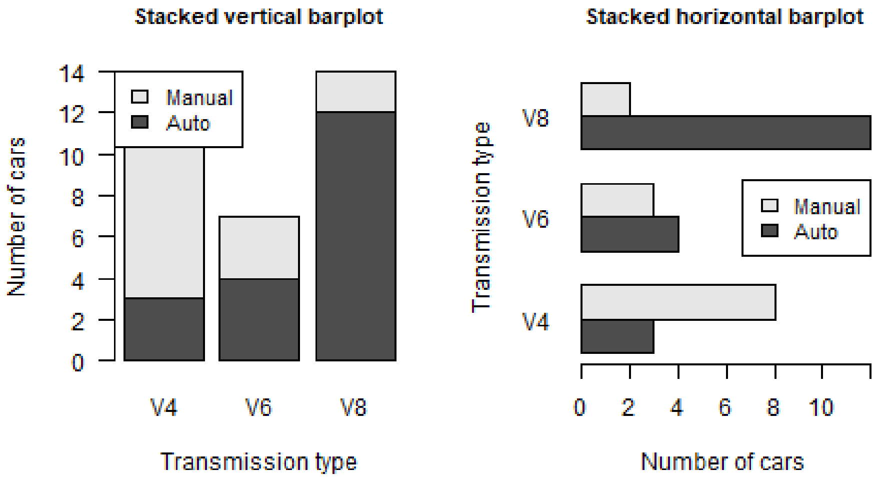


- Especially for stacked plots, it might be good to see the values attached to the bars. There is no parameter to do this, we must use `text`: the `labels` inside the function use the `numeric` values and convert them to `character` values for printing.

- For completeness: both final plots in a side-by-side plot array:

```
par(mfrow=c(1,2), pty='s')
barplot(cyl.freq.matrix,
        las = 1,
        xlab = "Transmission type",
        ylab = "Number of cars",
        names.arg = c("V4", "V6", "V8"),
        legend.text = c("Auto", "Manual"),
        args.legend = list(x="topleft",
                           cex=0.9))
title("Stacked vertical barplot",
      cex.main=0.9)
barplot(cyl.freq.matrix,
        las = 1,
        ylab = "Transmission type",
        xlab = "Number of cars",
        names.arg = c("V4", "V6", "V8"),
        legend.text = c("Auto", "Manual"),
        args.legend = list(x="right",
                           cex=0.9),
        horiz = TRUE,
        beside = TRUE)
```

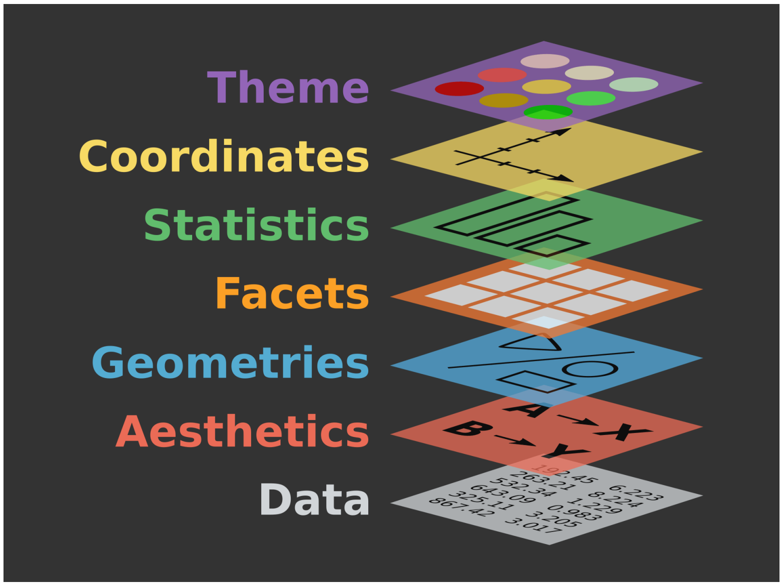
```
title("Stacked horizontal barplot",
      cex.main=0.9)
```



15 Barplots with ggplot2

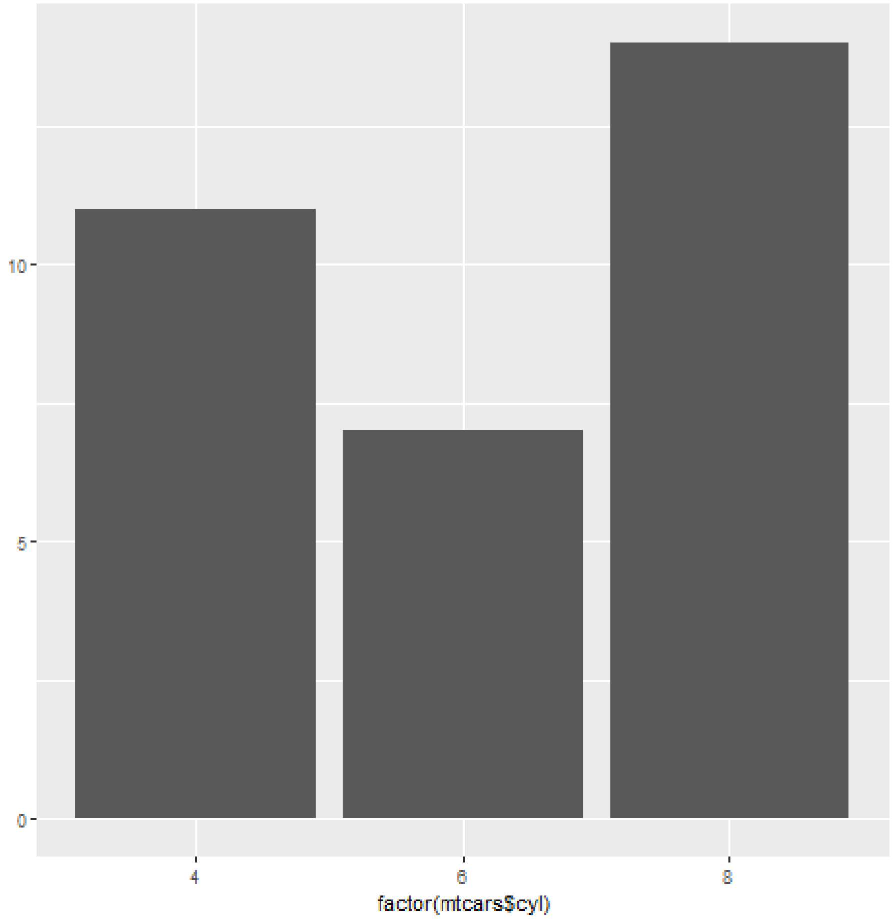
- The ggplot2 package is an alternative to base R plotting
- It it based on the "grammar of graphics" methodology: customization is layered on top of the raw data plot using the `+` operator

- You can use `ggplot` to make this plot but the layers stay the same



- Unlike base R, ggplot2 requires `data.frame` format, and is more picky
- The function `ggplot2::qplot` is a shortcut that looks like `plot`: the code below produces a basic barplot from `mtcars$cyl`

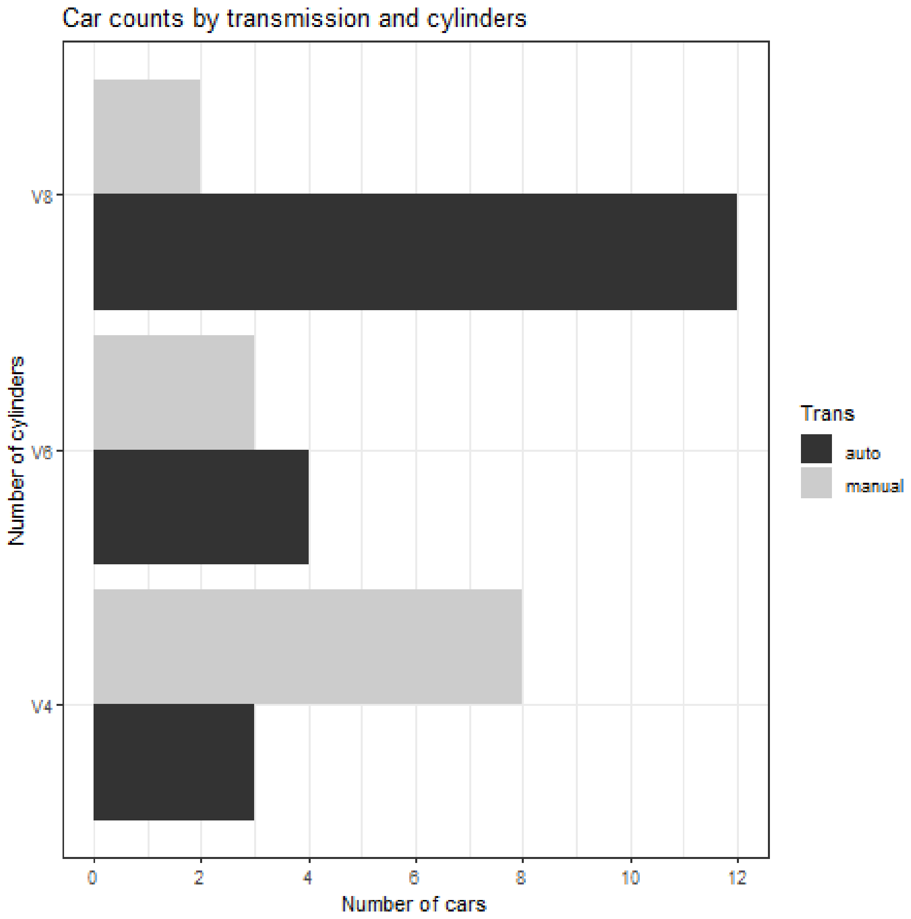
```
library(ggplot2)
qplot(factor(mtcars$cyl), geom="bar")
```



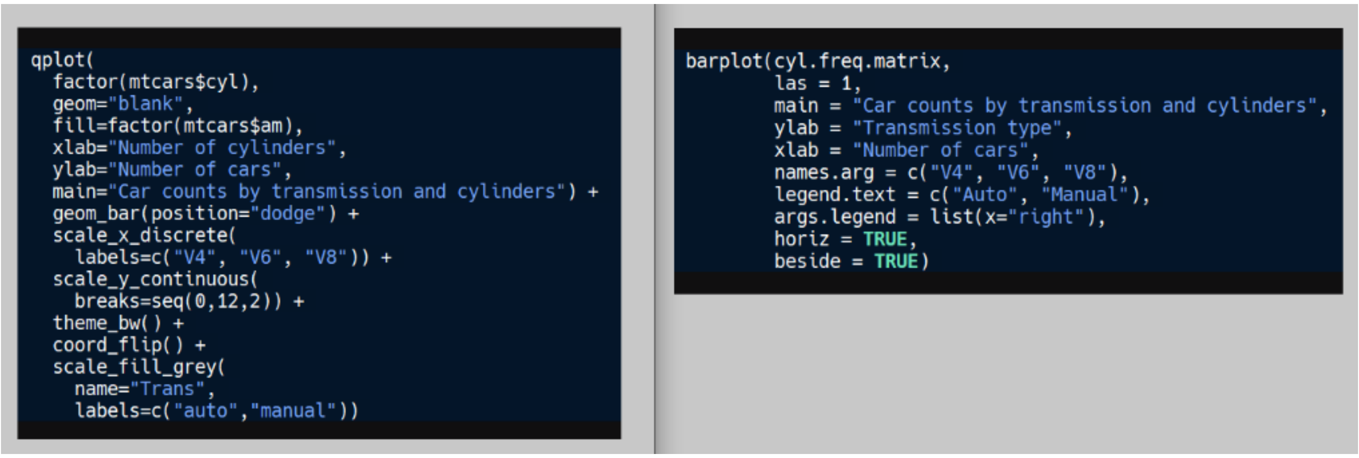
- Here, the relevant "geometry" is `"bar"` and the `numeric` variable must be supplied as a `factor` to allow treating it like a category
- To get this plot with `barplot` in base R, you need the frequency `table` function but you don't need to change the vector to `factor`

- To produce a ggplot2 version of the dodged barplot created earlier in base R, you can use this code:

```
qplot(
  factor(mtcars$cyl),
  geom="blank",
  fill=factor(mtcars$am),
  xlab="Number of cylinders",
  ylab="Number of cars",
  main="Car counts by transmission and cylinders") +
  geom_bar(position="dodge") +
  scale_x_discrete(
    labels=c("V4", "V6", "V8")) +
  scale_y_continuous(
    breaks=seq(0,12,2)) +
  coord_flip() +
  theme_bw() +
  scale_fill_grey(
    name="Trans",
    labels=c("auto","manual"))
```



- Direct contrast between ggplot2 and base R code: the default in ggplot2 is color (you can pick another theme)

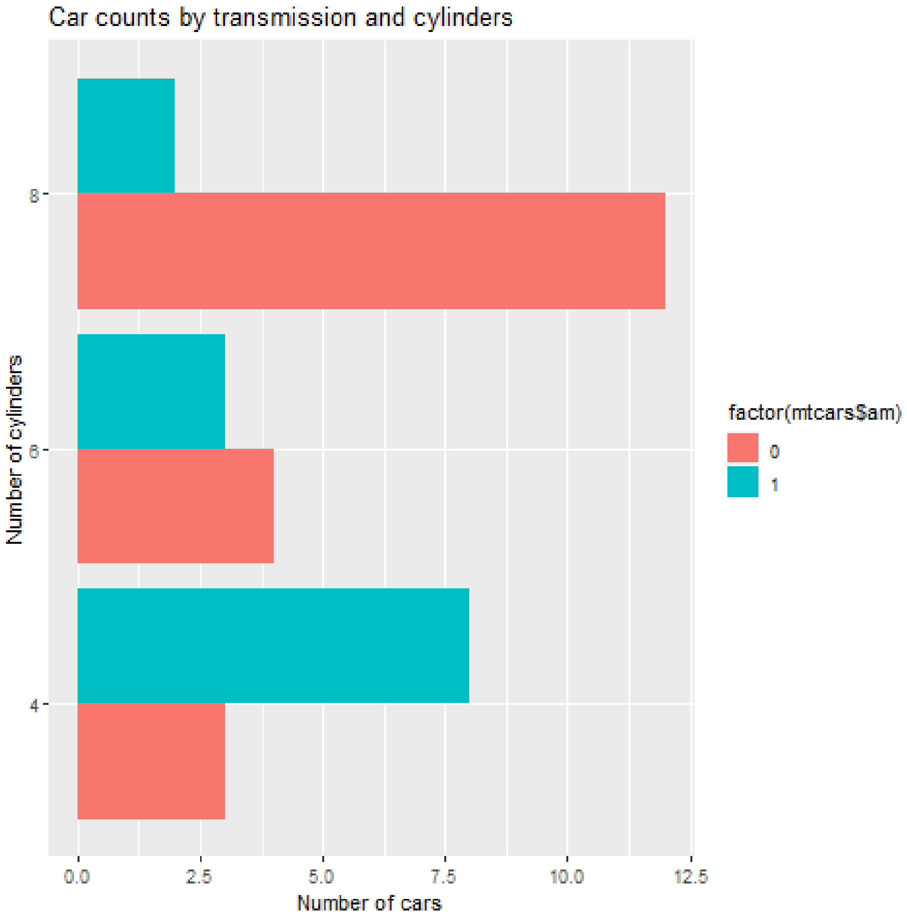


```
qplot(
  factor(mtcars$cyl),
  geom="blank",
  fill=factor(mtcars$am),
  xlab="Number of cylinders",
  ylab="Number of cars",
  main="Car counts by transmission and cylinders") +
  geom_bar(position="dodge") +
  scale_x_discrete(
    labels=c("V4", "V6", "V8")) +
  scale_y_continuous(
    breaks=seq(0,12,2)) +
  theme_bw() +
  coord_flip() +
  scale_fill_grey(
    name="Trans",
    labels=c("auto","manual"))
```

```
barplot(cyl.freq.matrix,
        las = 1,
        main = "Car counts by transmission and cylinders",
        ylab = "Transmission type",
        xlab = "Number of cars",
        names.arg = c("V4", "V6", "V8"),
        legend.text = c("Auto", "Manual"),
        args.legend = list(x="right"),
        horiz = TRUE,
        beside = TRUE)
```

- The default makes the code just as short as the base R solution:

```
qplot(
  factor(mtcars$cyl),
  geom="blank",
  fill=factor(mtcars$am),
  xlab="Number of cylinders",
  ylab="Number of cars",
  main="Car counts by transmission and cylinders") +
  geom_bar(position="dodge") +
  coord_flip()
```

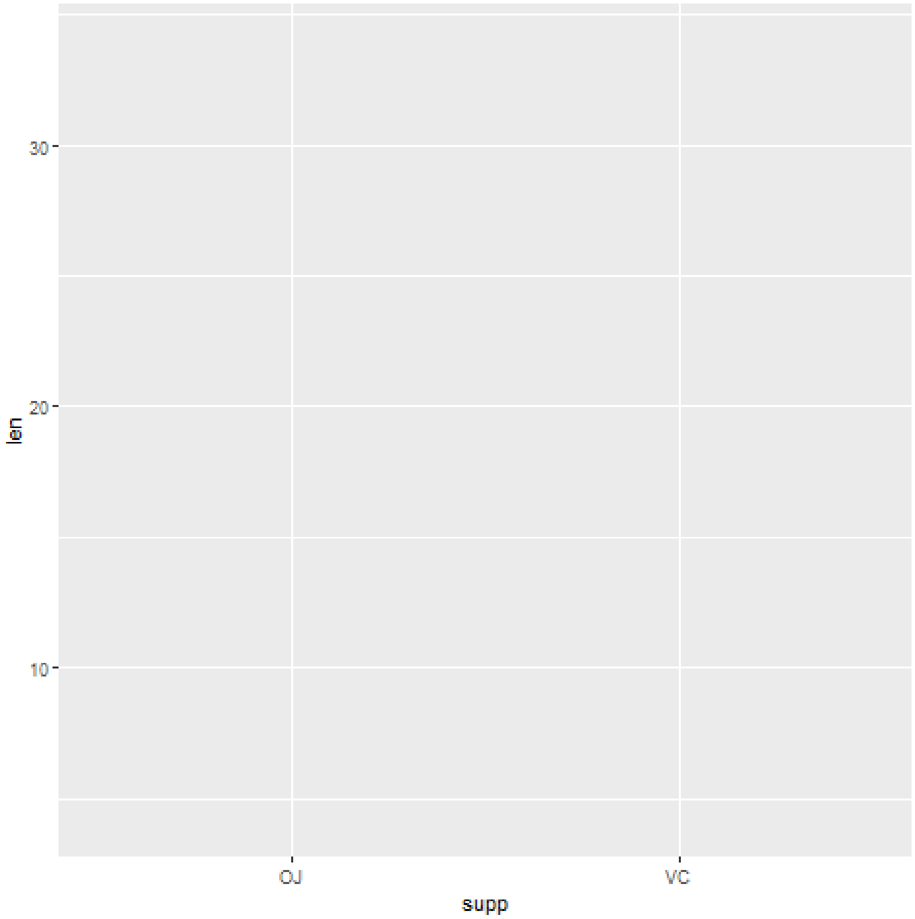


16 Practice ggplot2

Create a practice file `ggplot2.org` to work in: tinyurl.com/3pjpbyvz

1. Create barplot for the `ToothGrowth` dataset:
   - use the function `ggplot` with the arguments `data=ToothGrowth` and `aes(x=supp,y=len)`
   - store the plot in an object `p`
   - print `p`

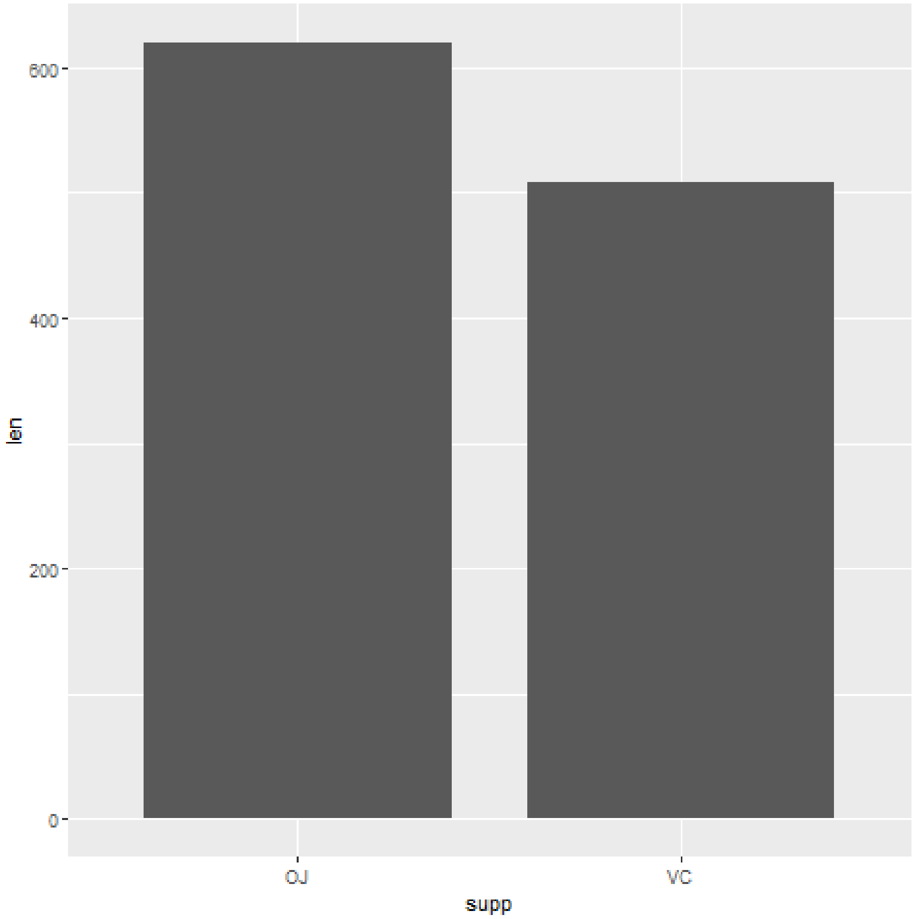
```
ggplot(
  data = ToothGrowth,
  aes(x=supp, y=len)) -> p
p
```



2. Add a barplot geometry layer to the plot `p`:

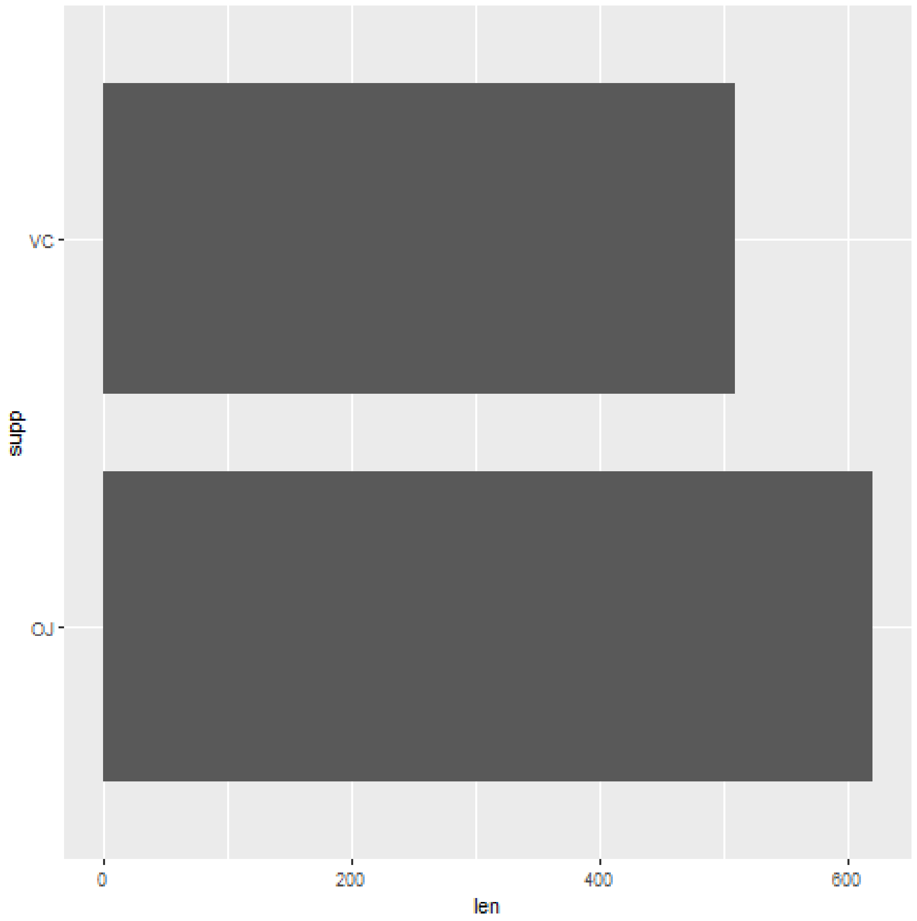
   - add (+) `geom_bar(stat="identity", width=0.8)`
   - store the new plot in `p1` and print it
   - note that adding with `+` on a new line gives an error!

```
p +
  geom_bar(
    stat="identity",
    width=0.8) -> p1
p1
```



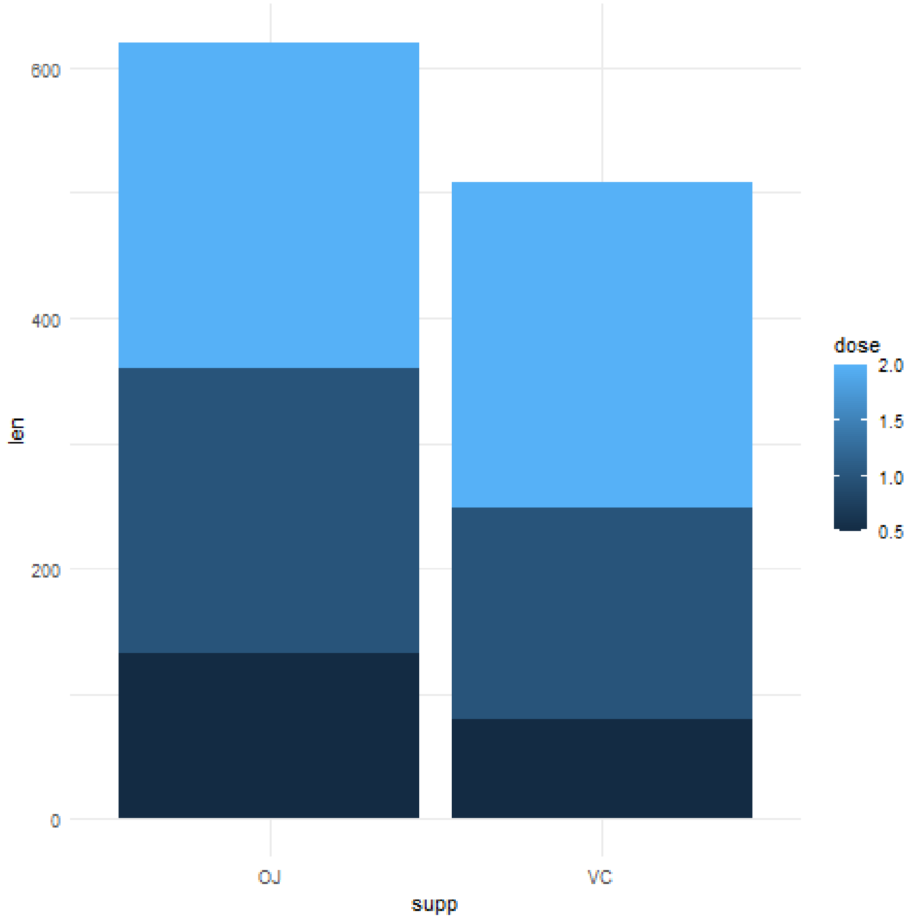
3. Turn the plot on its side:
   - Add `coord_flip()` to `p1`
   - Store it in `p2` and print it

```
p +
  geom_bar(
    stat="identity",
    width=0.8) +
  coord_flip() -> p2
p2
```



4. Using `ggplot`, make a stacked barplot of `ToothGrowth` which shows the dosage `dose` for each `supp` category, and add `theme_minimal`: save in `p3` and print plot

```
ggplot(
  data=ToothGrowth,
  aes(x=supp,
      y=len,
      fill=dose)) +
  geom_bar(stat="identity") +
  theme_minimal() -> p3
p3
```

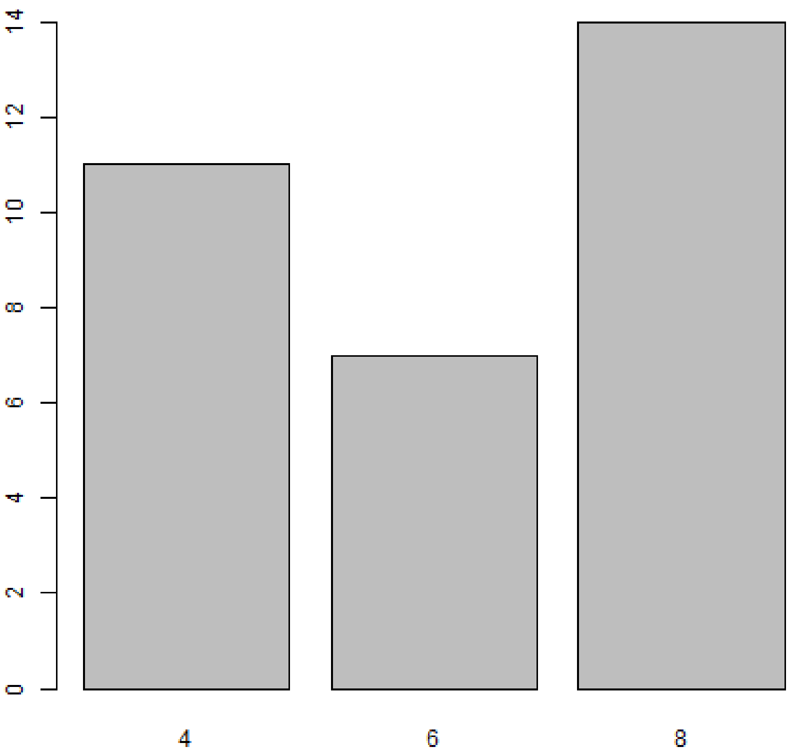


17 Pie charts with base R

- Pie charts are an alternative to visualizing category frequencies
- Pie slices represent relative counts of each categorical variable

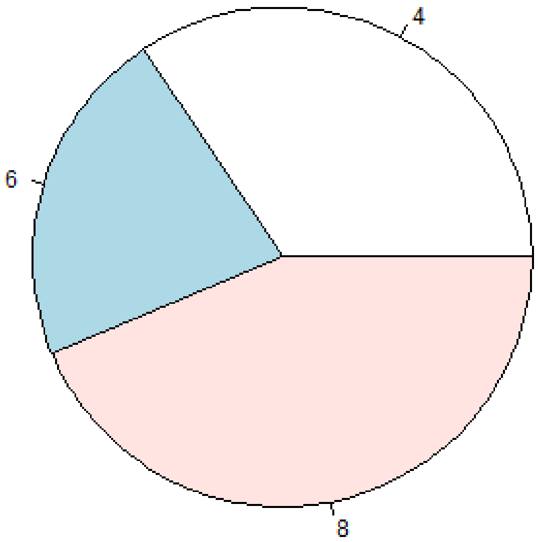
- Example: remember the `cylinders` in the `mtcars` data set?

```
cyl.freq <- table(mtcars$cyl)
barplot(height=cyl.freq)
```



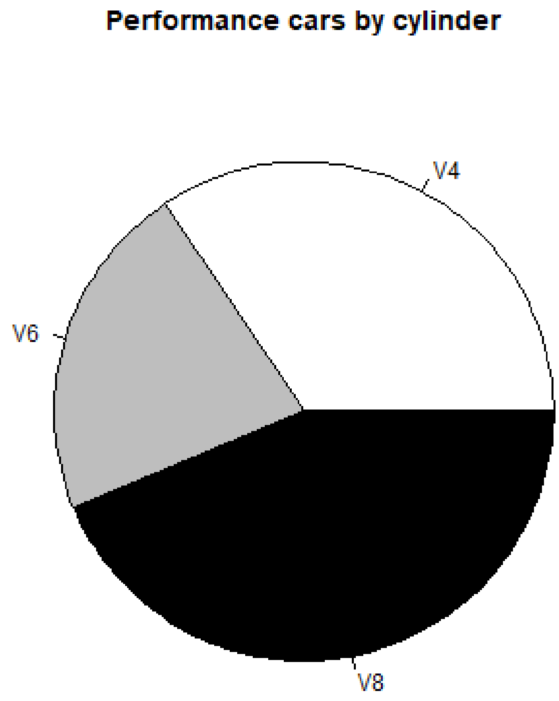
- Use `pie` to create a pie chart:

```
pie(x=cyl.freq)
```



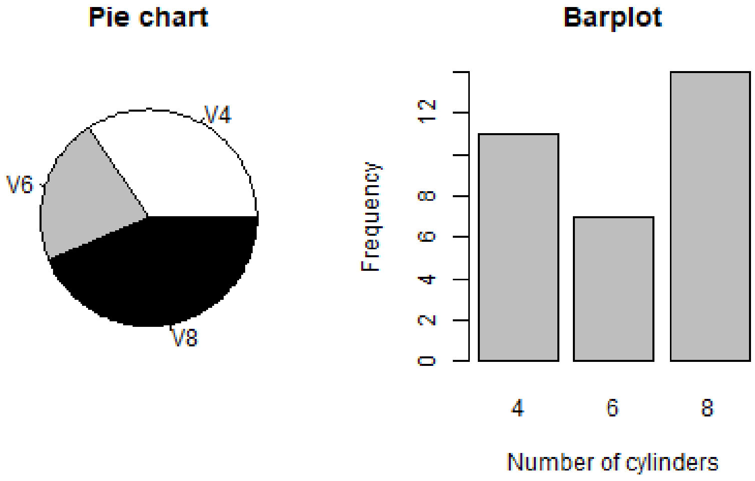
- Customize with parameters `label` (axis labels), `col` (color) and `main` (title):

```
pie(
  x = cyl.freq,
  labels = c("V4", "V6", "V8"),
  col = c("white","gray","black"),
  main = "Performance cars by cylinder")
```



- Both plots next to one another in a plot array

```
par(mfrow=c(1,2),pty='s')
cyl.freq <- table(mtcars$cyl)
pie(
  x = cyl.freq,
  labels = c("V4", "V6", "V8"),
  col = c("white","gray","black"),
  main = "Pie chart")
barplot(
  height = cyl.freq,
  main = "Barplot",
  xlab = "Number of cylinders",
  ylab = "Frequency"
)
```



18 Pie charts with ggplot2

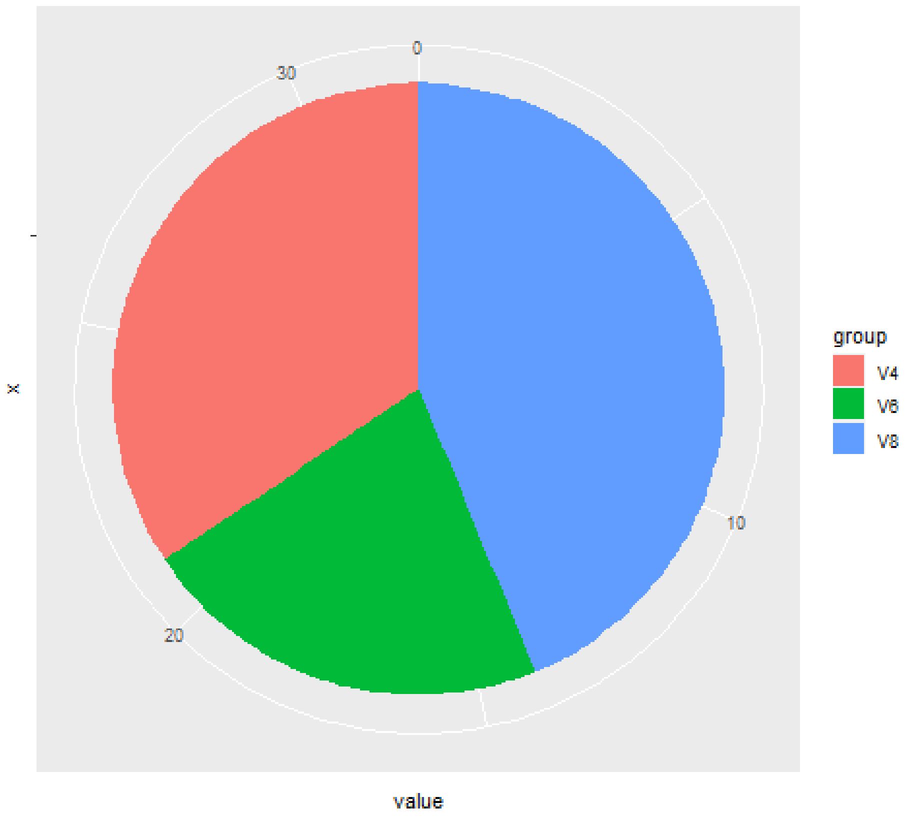
- There's no pie chart geometry in ggplot2, you have to improvise: first build the data frame to be plotted:

```
value <- c(sum(mtcars$cyl == "4"),
           sum(mtcars$cyl == "6"),
           sum(mtcars$cyl == "8"))
value
group <- c("V4","V6","V8")
group
data <- data.frame(value,group)
data
```

```
[1] 11  7 14
[1] "V4" "V6" "V8"
  value group
1    11    V4
2     7    V6
3    14    V8
```

- Then plot as a barplot with polar coordinates:

```
ggplot(data,
       aes(x="", y=value, fill=group)) +
  geom_bar(width=1, stat="identity") +
  coord_polar("y", start=0)
```



- Pie charts are only useful when you have few categories that are unordered. As soon as you want to display a second variable, or if you have more than a few levels, bar charts are to be preferred.

19 References

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

Footnotes:

[1] What are the categories used to organize the graphs? Distribution, correlation and evolution (aka growth) relate to statistical summaries. Spatial relates to an application, and the last ones are qualitative characteristics related to patterns (part/whole), order (ranking) and time (flow), showing special types of graphs (pie chart, spider graph and line graph). The "Miscellaneous" category is filled with fun examples, too.

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