Multivariate Data

2020

In this section we are going to review the relationship between more than 2 variables. The analysis follow the logic presented in univariate and bivariate data analysis section.

Categorical data

We have already reviewed frequency tables and proportion tables on 1 categorical variable and on 2 categorical variables using `table` and `prop.table` functions. It is the same for 3 and more categorical variables.

For the next examples let's consider `Cars93` data frame from `MASS` package presenting data from 93 cars on sale in the USA in 1993.

```
> library(MASS)
> attach(Cars93)
> head(Cars93)
  Manufacturer   Model    Type Min.Price Price Max.Price 
MPG.city MPG.highway
1        Acura Integra   Small      12.9  15.9      18.8
25          31
2        Acura  Legend Midsize      29.2  33.9      38.7
18          25
3         Audi      90 Compact      25.9  29.1      32.3
20          26
4         Audi     100 Midsize      30.8  37.7      44.6
19          26
5          BMW    535i Midsize      23.7  30.0      36.2
22          30
6        Buick Century Midsize      14.2  15.7      17.3
22          31
             AirBags DriveTrain Cylinders EngineSize 
Horsepower  RPM
1               None      Front         4        1.8
140 6300
```

```
2 Driver & Passenger       Front            6         3.2
200 5500
3          Driver only       Front            6         2.8
172 5500
4 Driver & Passenger       Front            6         2.8
172 5500
5          Driver only        Rear            4         3.5
208 5700
6          Driver only       Front            4         2.2
110 5200
  Rev.per.mile Man.trans.avail Fuel.tank.capacity
Passengers Length Wheelbase
1          2890               Yes                13.2
5     177         102
2          2335               Yes                18.0
5     195         115
3          2280               Yes                16.9
5     180         102
4          2535               Yes                21.1
6     193         106
5          2545               Yes                21.1
4     186         109
6          2565                No                16.4
6     189         105
  Width Turn.circle Rear.seat.room Luggage.room Weight
Origin           Make
1     68          37           26.5           11   2705
non-USA Acura Integra
2     71          38           30.0           15   3560
non-USA  Acura Legend
3     67          37           28.0           14   3375
non-USA       Audi 90
4     70          37           31.0           17   3405
non-USA      Audi 100
5     69          39           27.0           13   3640
non-USA      BMW 535i
6     69          41           28.0           16   2880
USA Buick Century
```

Car’s `Manufacturer`, `Origin`, `Type` and `AirBags` are categorical variables, so we can see their frequency tables

```
> table(Manufacturer)
Manufacturer
        Acura          Audi           BMW         Buick 
Cadillac 
            2             2             1             4 
2 
    Chevrolet       Chrylser      Chrysler         Dodge 
Eagle 
            8             1             2             6 
2 
         Ford           Geo         Honda       Hyundai 
Infiniti 
            8             2             3             4 
1 
        Lexus       Lincoln         Mazda Mercedes-Benz 
Mercury 
            2             2             5             2 
2 
   Mitsubishi        Nissan    Oldsmobile      Plymouth 
Pontiac 
            2             4             4             1 
5 
         Saab        Saturn        Subaru        Suzuki 
Toyota 
            1             1             3             1 
4 
   Volkswagen         Volvo 
            4             2 
> sort(table(Manufacturer), decreasing = TRUE)
Manufacturer
    Chevrolet          Ford         Dodge         Mazda 
Pontiac 
            8             8             6             5 
5 
        Buick       Hyundai        Nissan    Oldsmobile 
Toyota 
            4             4             4             4 
4 
   Volkswagen         Honda        Subaru         Acura 
Audi 
            4             3             3             2 
2 
```

```
     Cadillac      Chrysler         Eagle           Geo
Lexus
            2             2             2             2
2
      Lincoln Mercedes-Benz       Mercury    Mitsubishi
Volvo
            2             2             2             2
2
          BMW      Chrylser      Infiniti      Plymouth
Saab
            1             1             1             1
1
       Saturn        Suzuki
            1             1
```

In our data set most of the cars are manufactured by Chevrolet, Ford, Dodge.

```
> table(Origin)
Origin
    USA non-USA
     48      45
> table(Origin) / length(Origin)
Origin
     USA  non-USA
0.516129 0.483871
> prop.table(table(Origin))
Origin
     USA  non-USA
0.516129 0.483871
> table(Type)
Type
Compact   Large Midsize   Small  Sporty     Van
     16      11      22      21      14       9
> sort(table(Type), decreasing = TRUE)
Type
Midsize   Small Compact  Sporty   Large     Van
     22      21      16      14      11       9
> Type <- factor(Type, levels = c("Small", "Compact",
"Midsize", "Large", "Sporty", "Van"))
> table(Type)
Type
```

```
  Small Compact Midsize   Large  Sporty     Van 
     21      16      22      11      14       9
```

Most of the cars in our data set are middle and small size.

```
> table(AirBags)
AirBags
Driver & Passenger        Driver only               None 
                16                 43                 34
> sort(table(AirBags), decreasing = TRUE)
AirBags
       Driver only               None Driver & Passenger 
                43                 34                 16
```

Most of the cars in our data set are with airbag only for the driver

We can also see how the cars from one manufacturer are distributed upon origin, type and airbag type.

```
> table(Origin, Manufacturer)
         Manufacturer
Origin    Acura Audi BMW Buick Cadillac Chevrolet 
Chrylser Chrysler Dodge Eagle
  USA         0    0   0     4        2         8
1        2     6     2
  non-USA     2    2   1     0        0         0
0        0     0     0
         Manufacturer
Origin    Ford Geo Honda Hyundai Infiniti Lexus Lincoln 
Mazda Mercedes-Benz
  USA        8   0     0       0        0     0       2
0             0
  non-USA    0   2     3       4        1     2       0
5             2
         Manufacturer
Origin    Mercury Mitsubishi Nissan Oldsmobile Plymouth 
Pontiac Saab Saturn
  USA           2          0      0          4        1
5       0      1
  non-USA       0          2      4          0        0
0       1      0
         Manufacturer
Origin    Subaru Suzuki Toyota Volkswagen Volvo
```

```
  USA             0      0      0          0     0
  non-USA         3      1      4          4     2
> table(Type, Manufacturer)
         Manufacturer
Type      Acura Audi BMW Buick Cadillac Chevrolet 
Chrylser Chrysler Dodge Eagle
  Small         1    0   0     0        0         0
0        0      2     1
  Compact       0    1   0     0        0         2
0        1      1     0
  Midsize       1    1   1     2        1         1
0        0      1     0
  Large         0    0   0     2        1         1
1        1      0     1
  Sporty        0    0   0     0        0         2
0        0      1     0
  Van           0    0   0     0        0         2
0        0      1     0
         Manufacturer
Type      Ford Geo Honda Hyundai Infiniti Lexus Lincoln 
Mazda Mercedes-Benz
  Small      2   1     1       2        0     0       0
2             0
  Compact    1   0     1       0        0     0       0
1             1
  Midsize    1   0     0       1        1     2       1
0             1
  Large      1   0     0       0        0     0       1
0             0
  Sporty     2   1     1       1        0     0       0
1             0
  Van        1   0     0       0        0     0       0
1             0
         Manufacturer
Type      Mercury Mitsubishi Nissan Oldsmobile Plymouth 
Pontiac Saab Saturn
  Small         0          1      1          0        0
1       0    1
  Compact       0          0      1          1        0
1       1    0
  Midsize       1          1      1          1        0
1       0    0
```

```
  Large            0          0      0          1        0
1    0      0
  Sporty           1          0      0          0        1
1    0      0
  Van              0          0      1          1        0
0    0      0
         Manufacturer
Type      Subaru Suzuki Toyota Volkswagen Volvo
  Small        2      1      1          1     0
  Compact      1      0      0          1     1
  Midsize      0      0      1          0     1
  Large        0      0      0          0     0
  Sporty       0      0      1          1     0
  Van          0      0      1          1     0
> table(AirBags, Manufacturer)
                    Manufacturer
AirBags              Acura Audi BMW Buick Cadillac 
Chevrolet Chrylser Chrysler
  Driver & Passenger     1    1   0     0        1
1         1        1
  Driver only            0    1   1     4        1
3         0        1
  None                   1    0   0     0        0
4         0        0
                    Manufacturer
AirBags              Dodge Eagle Ford Geo Honda Hyundai 
Infiniti Lexus Lincoln
  Driver & Passenger     0     1    0   0     2       0
0      1       2
  Driver only            5     0    5   1     1       0
1      1       0
  None                   1     1    3   1     0       4
0      0       0
                    Manufacturer
AirBags              Mazda Mercedes-Benz Mercury 
Mitsubishi Nissan Oldsmobile
  Driver & Passenger     0             1       0
0          0          0
  Driver only            2             1       1
1          3          2
  None                   3             0       1
1          1          2
```

```
                    Manufacturer
AirBags              Plymouth Pontiac Saab Saturn Subaru 
Suzuki Toyota
  Driver & Passenger        0       2    0      0      0      
0      0
  Driver only               0       0    1      1      1      
0      4
  None                      1       3    0      0      2      
1      0
                    Manufacturer
AirBags              Volkswagen Volvo
  Driver & Passenger          0     1
  Driver only                 0     1
  None                        4     0
```

Let's see how the different car types are distributed upon different origins and airbag types. We will also show their proportion tables.

By default significant digits are 7, for the next examples let's set them to 2.

```
> getOption("digits")
[1] 7
> options(digits = 2)
> table(Origin, Type)
         Type
Origin    Small Compact Midsize Large Sporty Van
  USA         7       7      10    11      8   5
  non-USA    14       9      12     0      6   4
> prop.table(table(Origin, Type))
         Type
Origin    Small Compact Midsize Large Sporty   Van
  USA     0.075   0.075   0.108 0.118  0.086 0.054
  non-USA 0.151   0.097   0.129 0.000  0.065 0.043
> prop.table(table(Origin, Type), 1)
         Type
Origin    Small Compact Midsize Large Sporty   Van
  USA     0.146   0.146   0.208 0.229  0.167 0.104
  non-USA 0.311   0.200   0.267 0.000  0.133 0.089
> prop.table(table(Origin, Type), 2)
         Type
Origin    Small Compact Midsize Large Sporty  Van
  USA      0.33    0.44    0.45  1.00   0.57 0.56
```

```
  non-USA  0.67     0.56     0.55  0.00    0.43 0.44
> table(AirBags, Type)
                    Type
AirBags               Small Compact Midsize Large Sporty
Van
  Driver & Passenger     0       2       7     4      3
0
  Driver only            5       9      11     7      8
3
  None                  16       5       4     0      3
6
> prop.table(table(AirBags, Type))
                    Type
AirBags               Small Compact Midsize Large Sporty
Van
  Driver & Passenger 0.000   0.022   0.075 0.043  0.032
0.000
  Driver only        0.054   0.097   0.118 0.075  0.086
0.032
  None               0.172   0.054   0.043 0.000  0.032
0.065
> prop.table(table(AirBags, Type), 1)
                    Type
AirBags               Small Compact Midsize Large Sporty
Van
  Driver & Passenger 0.000   0.125   0.438 0.250  0.188
0.000
  Driver only        0.116   0.209   0.256 0.163  0.186
0.070
  None               0.471   0.147   0.118 0.000  0.088
0.176
> prop.table(table(AirBags, Type), 2)
                    Type
AirBags               Small Compact Midsize Large Sporty
Van
  Driver & Passenger  0.00    0.12    0.32  0.36   0.21
0.00
  Driver only         0.24    0.56    0.50  0.64   0.57
0.33
  None                0.76    0.31    0.18  0.00   0.21
0.67
```

We can see that most of the Small and Van cars in our data set don't have an airbag, more than one half of the others have airbag only for the driver and 44% of the cars that have airbag for the driver and passenger are with midsize type and we don't have cars from the small and Van type that have airbag for the driver and passenger.

Similarly we can generate a frequency table for 3 and more categorical variables.

```
> table(DriveTrain, Type, Man.trans.avail)
, , Man.trans.avail = No

          Type
DriveTrain Small Compact Midsize Large Sporty Van
     4WD       0       0       0     0      0   3
     Front     0       2      10     7      0   3
     Rear      0       0       3     4      0   0

, , Man.trans.avail = Yes

          Type
DriveTrain Small Compact Midsize Large Sporty Van
     4WD       2       1       0     0      2   2
     Front    19      11       7     0      7   1
     Rear      0       2       2     0      5   0
```

We can also use `xtabs` function with the formula syntax

```
> xtabs(~Type)
Type
  Small Compact Midsize   Large  Sporty     Van 
     21      16      22      11      14       9
> xtabs(~Manufacturer+Type)
               Type
Manufacturer    Small Compact Midsize Large Sporty Van
  Acura             1       0       1     0      0   0
  Audi              0       1       1     0      0   0
  BMW               0       0       1     0      0   0
  Buick             0       0       2     2      0   0
  Cadillac          0       0       1     1      0   0
  Chevrolet         0       2       1     1      2   2
  Chrylser          0       0       0     1      0   0
```

```
  Chrysler                0        1        0      1        0    0
  Dodge                   2        1        1      0        1    1
  Eagle                   1        0        0      1        0    0
  Ford                    2        1        1      1        2    1
  Geo                     1        0        0      0        1    0
  Honda                   1        1        0      0        1    0
  Hyundai                 2        0        1      0        1    0
  Infiniti                0        0        1      0        0    0
  Lexus                   0        0        2      0        0    0
  Lincoln                 0        0        1      1        0    0
  Mazda                   2        1        0      0        1    1
  Mercedes-Benz           0        1        1      0        0    0
  Mercury                 0        0        1      0        1    0
  Mitsubishi              1        0        1      0        0    0
  Nissan                  1        1        1      0        0    1
  Oldsmobile              0        1        1      1        0    1
  Plymouth                0        0        0      0        1    0
  Pontiac                 1        1        1      1        1    0
  Saab                    0        1        0      0        0    0
  Saturn                  1        0        0      0        0    0
  Subaru                  2        1        0      0        0    0
  Suzuki                  1        0        0      0        0    0
  Toyota                  1        0        1      0        1    1
  Volkswagen              1        1        0      0        1    1
  Volvo                   0        1        1      0        0    0
> xtabs(~Manufacturer+AirBags)
               AirBags
Manufacturer     Driver & Passenger Driver only None
  Acura                           1           0    1
  Audi                            1           1    0
  BMW                             0           1    0
  Buick                           0           4    0
  Cadillac                        1           1    0
  Chevrolet                       1           3    4
  Chrylser                        1           0    0
  Chrysler                        1           1    0
  Dodge                           0           5    1
  Eagle                           1           0    1
  Ford                            0           5    3
  Geo                             0           1    1
  Honda                           2           1    0
  Hyundai                         0           0    4
```

```
  Infiniti                          0           1    0
  Lexus                             1           1    0
  Lincoln                           2           0    0
  Mazda                             0           2    3
  Mercedes-Benz                     1           1    0
  Mercury                           0           1    1
  Mitsubishi                        0           1    1
  Nissan                            0           3    1
  Oldsmobile                        0           2    2
  Plymouth                          0           0    1
  Pontiac                           2           0    3
  Saab                              0           1    0
  Saturn                            0           1    0
  Subaru                            0           1    2
  Suzuki                            0           0    1
  Toyota                            0           4    0
  Volkswagen                        0           0    4
  Volvo                             1           1    0
> xtabs(~AirBags+Type)
                    Type
AirBags              Small Compact Midsize Large Sporty 
Van
  Driver & Passenger     0       2       7     4      3 
0
  Driver only            5       9      11     7      8 
3
  None                  16       5       4     0      3 
6
```

or `ftable` function

```
> ftable(Type)
Type Small Compact Midsize Large Sporty Van

        21      16      22    11     14   9
> ftable(Manufacturer, Type)
              Type Small Compact Midsize Large Sporty Van
Manufacturer
Acura                  1       0       1     0      0   0
Audi                   0       1       1     0      0   0
BMW                    0       0       1     0      0   0
Buick                  0       0       2     2      0   0
```

```
Cadillac               0       0       1      1      0   0
Chevrolet              0       2       1      1      2   2
Chrylser               0       0       0      1      0   0
Chrysler               0       1       0      1      0   0
Dodge                  2       1       1      0      1   1
Eagle                  1       0       0      1      0   0
Ford                   2       1       1      1      2   1
Geo                    1       0       0      0      1   0
Honda                  1       1       0      0      1   0
Hyundai                2       0       1      0      1   0
Infiniti               0       0       1      0      0   0
Lexus                  0       0       2      0      0   0
Lincoln                0       0       1      1      0   0
Mazda                  2       1       0      0      1   1
Mercedes-Benz          0       1       1      0      0   0
Mercury                0       0       1      0      1   0
Mitsubishi             1       0       1      0      0   0
Nissan                 1       1       1      0      0   1
Oldsmobile             0       1       1      1      0   1
Plymouth               0       0       0      0      1   0
Pontiac                1       1       1      1      1   0
Saab                   0       1       0      0      0   0
Saturn                 1       0       0      0      0   0
Subaru                 2       1       0      0      0   0
Suzuki                 1       0       0      0      0   0
Toyota                 1       0       1      0      1   1
Volkswagen             1       1       0      0      1   1
Volvo                  0       1       1      0      0   0
> ftable(Manufacturer, AirBags)
              AirBags Driver & Passenger Driver only None
Manufacturer
Acura                                  1           0    1
Audi                                   1           1    0
BMW                                    0           1    0
Buick                                  0           4    0
Cadillac                               1           1    0
Chevrolet                              1           3    4
Chrylser                               1           0    0
Chrysler                               1           1    0
Dodge                                  0           5    1
Eagle                                  1           0    1
Ford                                   0           5    3
```

```
Geo                                    0           1    1
Honda                                  2           1    0
Hyundai                                0           0    4
Infiniti                               0           1    0
Lexus                                  1           1    0
Lincoln                                2           0    0
Mazda                                  0           2    3
Mercedes-Benz                          1           1    0
Mercury                                0           1    1
Mitsubishi                             0           1    1
Nissan                                 0           3    1
Oldsmobile                             0           2    2
Plymouth                               0           0    1
Pontiac                                2           0    3
Saab                                   0           1    0
Saturn                                 0           1    0
Subaru                                 0           1    2
Suzuki                                 0           0    1
Toyota                                 0           4    0
Volkswagen                             0           0    4
Volvo                                  1           1    0
> ftable(AirBags, Type)
                   Type Small Compact Midsize Large
Sporty Van
AirBags
Driver & Passenger          0       2       7     4
3   0
Driver only                 5       9      11     7
8   3
None                       16       5       4     0
3   6
> ftable(Manufacturer, AirBags, Type)
                                 Type Small Compact
Midsize Large Sporty Van
Manufacturer  AirBags
Acura         Driver & Passenger          0       0
1     0      0   0
              Driver only                 0       0
0     0      0   0
              None                        1       0
0     0      0   0
```

Audi	Driver & Passenger	0	0	1	0	0	0
	Driver only	0	1	0	0	0	0
	None	0	0	0	0	0	0
BMW	Driver & Passenger	0	0	0	0	0	0
	Driver only	0	0	1	0	0	0
	None	0	0	0	0	0	0
Buick	Driver & Passenger	0	0	0	0	0	0
	Driver only	0	0	2	2	0	0
	None	0	0	0	0	0	0
Cadillac	Driver & Passenger	0	0	1	0	0	0
	Driver only	0	0	0	1	0	0
	None	0	0	0	0	0	0
Chevrolet	Driver & Passenger	0	0	0	0	1	0
	Driver only	0	1	0	1	1	0
	None	0	1	1	0	0	2
Chrylser	Driver & Passenger	0	0	0	1	0	0
	Driver only	0	0	0	0	0	0
	None	0	0	0	0	0	0
Chrysler	Driver & Passenger	0	1	0	0	0	0
	Driver only	0	0	0	1	0	0
	None	0	0	0	0	0	0

Dodge	Driver & Passenger	0	0	0	0	0	0
	Driver only	1	1	1	0	1	1
	None	1	0	0	0	0	0
Eagle	Driver & Passenger	0	0	0	1	0	0
	Driver only	0	0	0	0	0	0
	None	1	0	0	0	0	0
Ford	Driver & Passenger	0	0	0	0	0	0
	Driver only	0	0	1	1	2	1
	None	2	1	0	0	0	0
Geo	Driver & Passenger	0	0	0	0	0	0
	Driver only	0	0	0	0	1	0
	None	1	0	0	0	0	0
Honda	Driver & Passenger	0	1	0	0	1	0
	Driver only	1	0	0	0	0	0
	None	0	0	0	0	0	0
Hyundai	Driver & Passenger	0	0	0	0	0	0
	Driver only	0	0	0	0	0	0
	None	2	0	1	0	1	0
Infiniti	Driver & Passenger	0	0	0	0	0	0
	Driver only	0	0	1	0	0	0
	None	0	0	0	0	0	0

Lexus	Driver & Passenger	0	0	1	0	0	0
	Driver only	0	0	1	0	0	0
	None	0	0	0	0	0	0
Lincoln	Driver & Passenger	0	0	1	1	0	0
	Driver only	0	0	0	0	0	0
	None	0	0	0	0	0	0
Mazda	Driver & Passenger	0	0	0	0	0	0
	Driver only	0	1	0	0	1	0
	None	2	0	0	0	0	1
Mercedes-Benz	Driver & Passenger	0	0	1	0	0	0
	Driver only	0	1	0	0	0	0
	None	0	0	0	0	0	0
Mercury	Driver & Passenger	0	0	0	0	0	0
	Driver only	0	0	0	0	1	0
	None	0	0	1	0	0	0
Mitsubishi	Driver & Passenger	0	0	0	0	0	0
	Driver only	0	0	1	0	0	0
	None	1	0	0	0	0	0
Nissan	Driver & Passenger	0	0	0	0	0	0
	Driver only	1	1	1	0	0	0
	None	0	0	0	0	0	1

Oldsmobile	Driver & Passenger	0	0	0	0	0	0
	Driver only	0	0	1	1	0	0
	None	0	1	0	0	0	1
Plymouth	Driver & Passenger	0	0	0	0	0	0
	Driver only	0	0	0	0	0	0
	None	0	0	0	0	1	0
Pontiac	Driver & Passenger	0	0	0	1	1	0
	Driver only	0	0	0	0	0	0
	None	1	1	1	0	0	0
Saab	Driver & Passenger	0	0	0	0	0	0
	Driver only	0	1	0	0	0	0
	None	0	0	0	0	0	0
Saturn	Driver & Passenger	0	0	0	0	0	0
	Driver only	1	0	0	0	0	0
	None	0	0	0	0	0	0
Subaru	Driver & Passenger	0	0	0	0	0	0
	Driver only	0	1	0	0	0	0
	None	2	0	0	0	0	0
Suzuki	Driver & Passenger	0	0	0	0	0	0
	Driver only	0	0	0	0	0	0
	None	1	0	0	0	0	0

```
Toyota        Driver & Passenger        0        0
0      0       0    0
              Driver only               1        0
1      0       1    1
              None                      0        0
0      0       0    0
Volkswagen    Driver & Passenger        0        0
0      0       0    0
              Driver only               0        0
0      0       0    0
              None                      1        1
0      0       1    1
Volvo         Driver & Passenger        0        0
1      0       0    0
              Driver only               0        1
0      0       0    0
              None                      0        0
0      0       0    0
```

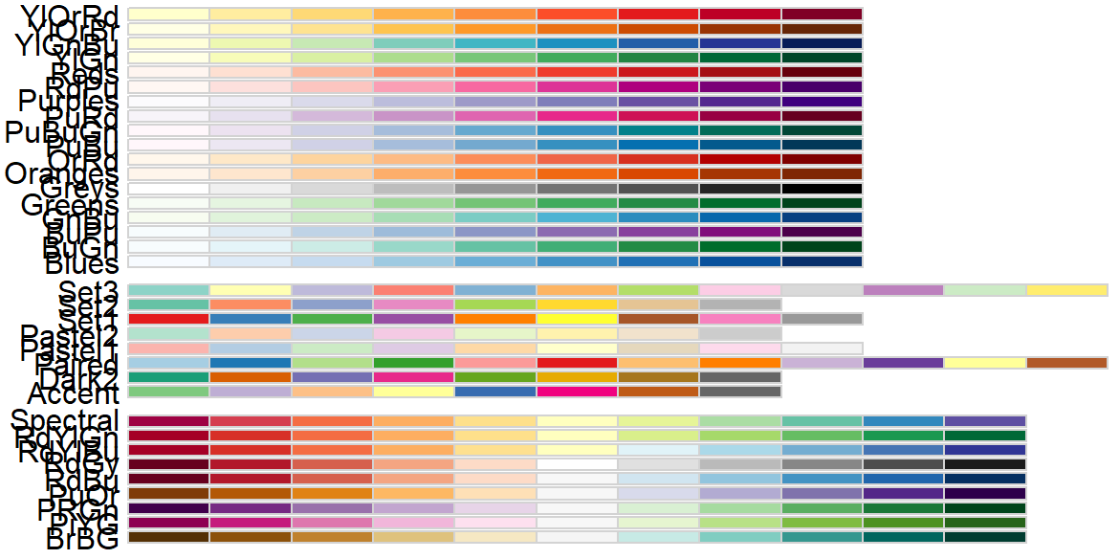
The plots that we use for categorical variables are barplot and piechart.

We are going to use `RColorBrewer` package for some predefined color palettes.

```
> install.packages("RColorBrewer")
> ? RColorBrewer
```

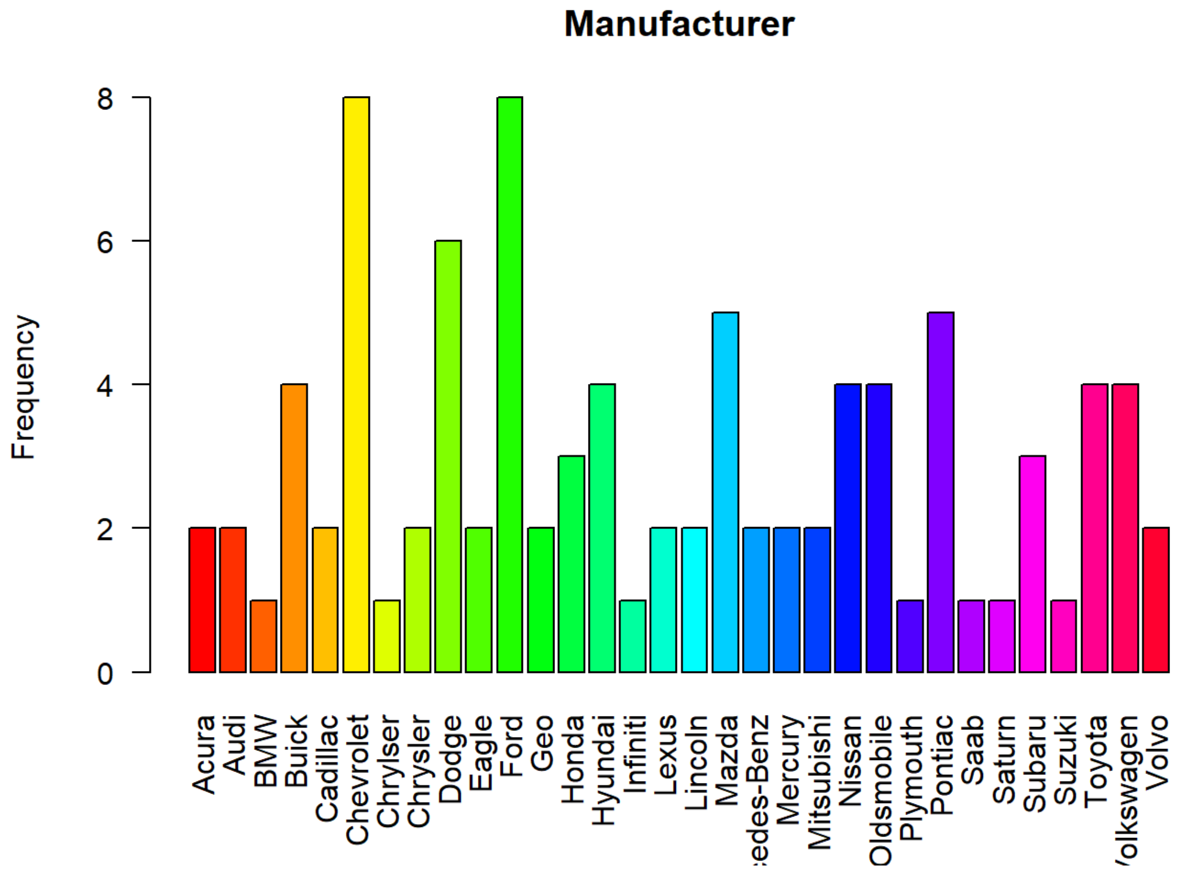
You can visualize the palettes using the `display.brewer.all()` function.

```r
> library(RColorBrewer)
> display.brewer.all()
```

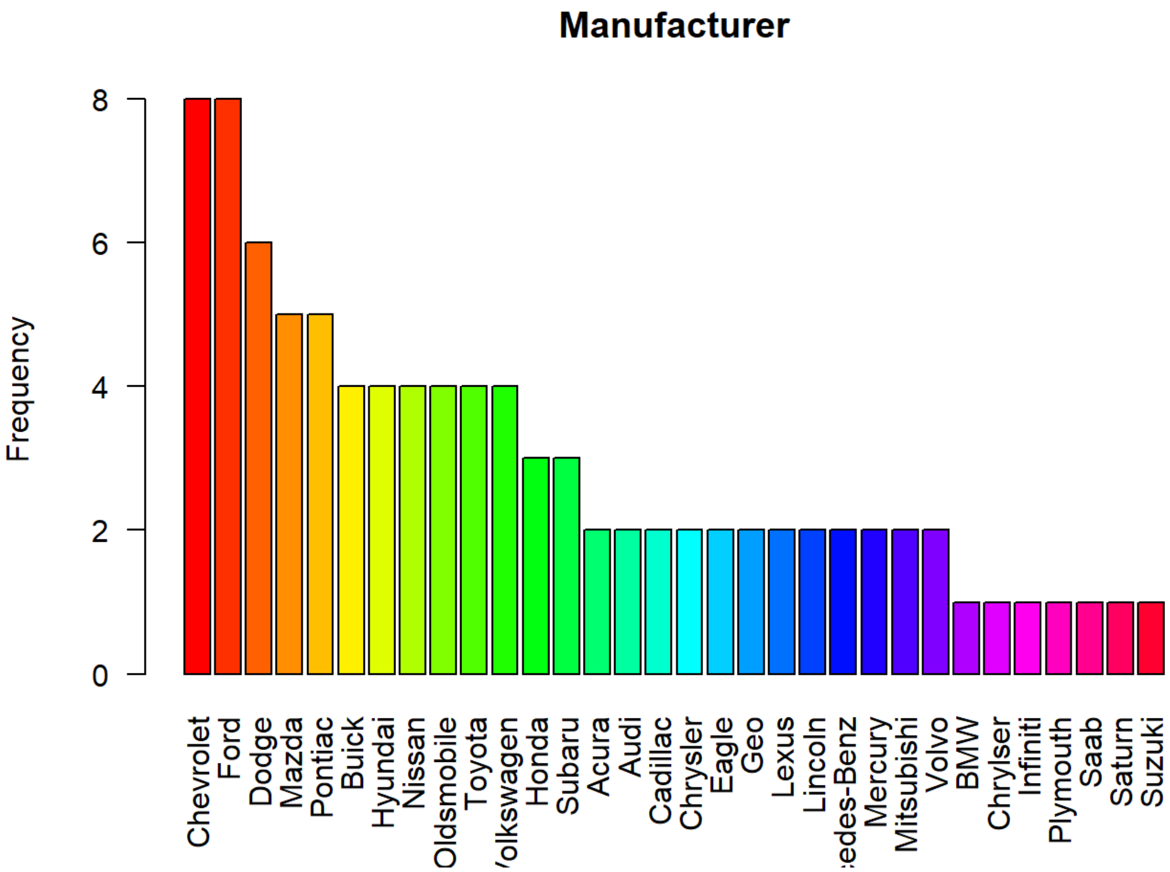


Following are the barplots of these categorical variables.

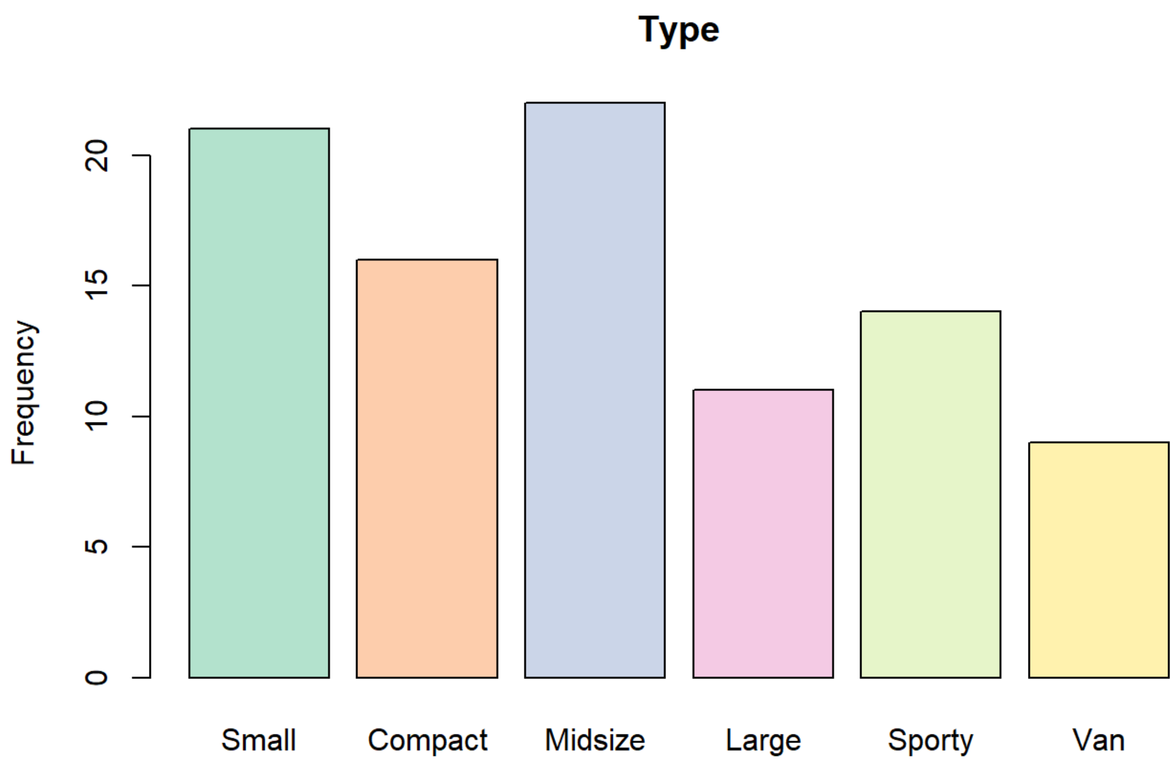
```
> barplot(table(Manufacturer),
+         main = "Manufacturer",
+         ylab = "Frequency",
+         las = 2,
+         col = rainbow(length(levels(Manufacturer))))
```



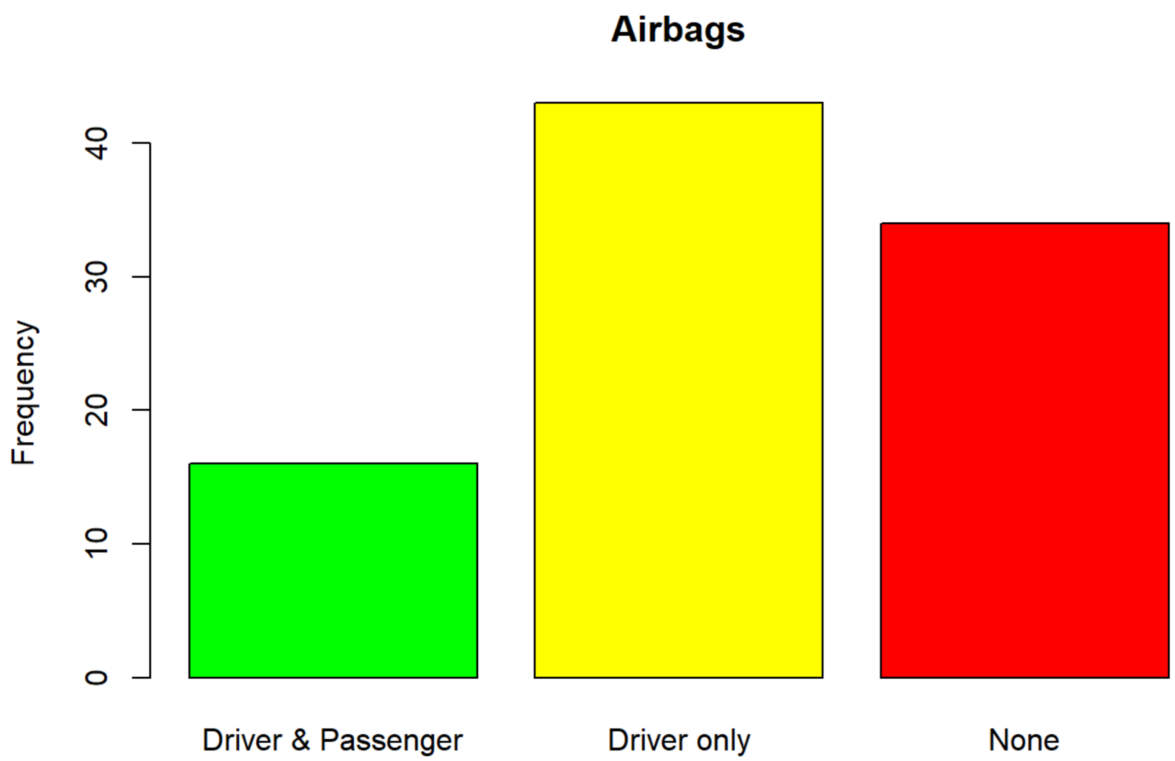
```r
> barplot(sort(table(Manufacturer), decreasing = TRUE),
+         main = "Manufacturer",
+         ylab = "Frequency",
+         las = 2,
+         col = rainbow(length(levels(Manufacturer))))
```



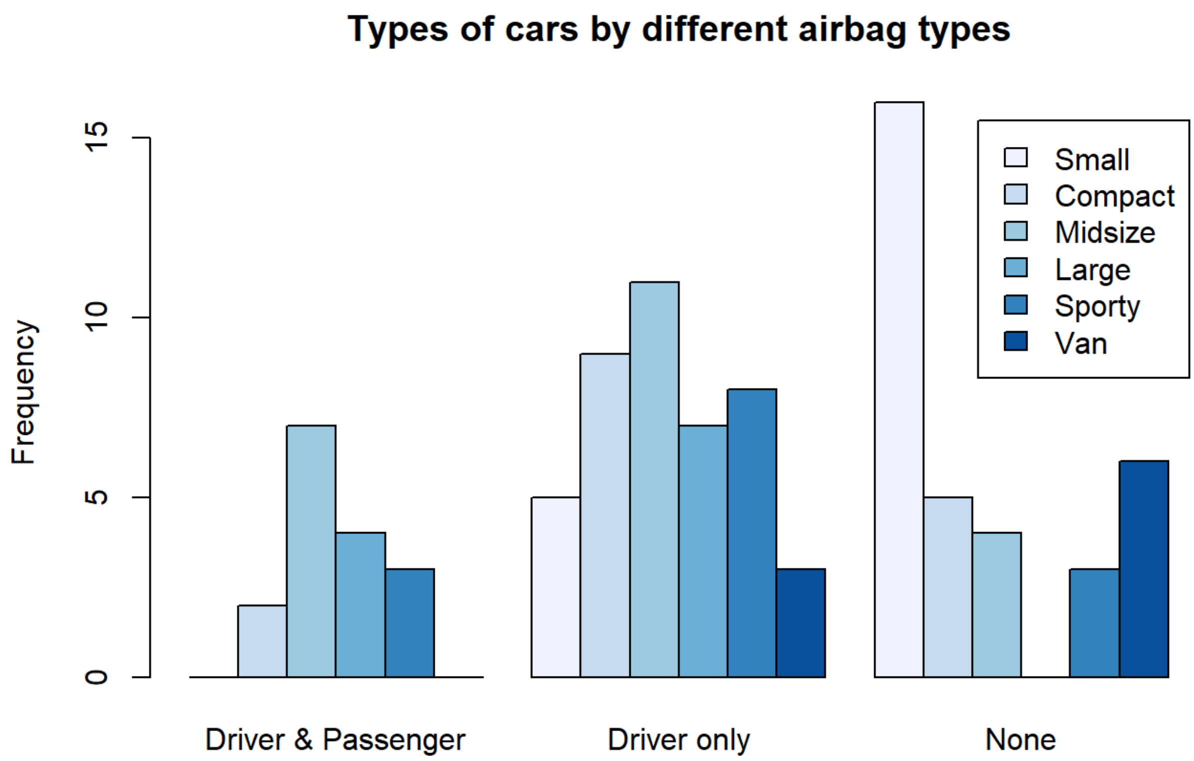
```
> barplot(table(Type),
+         main = "Type",
+         ylab = "Frequency",
+         col = brewer.pal(n = 6, name = "Pastel2"))
```



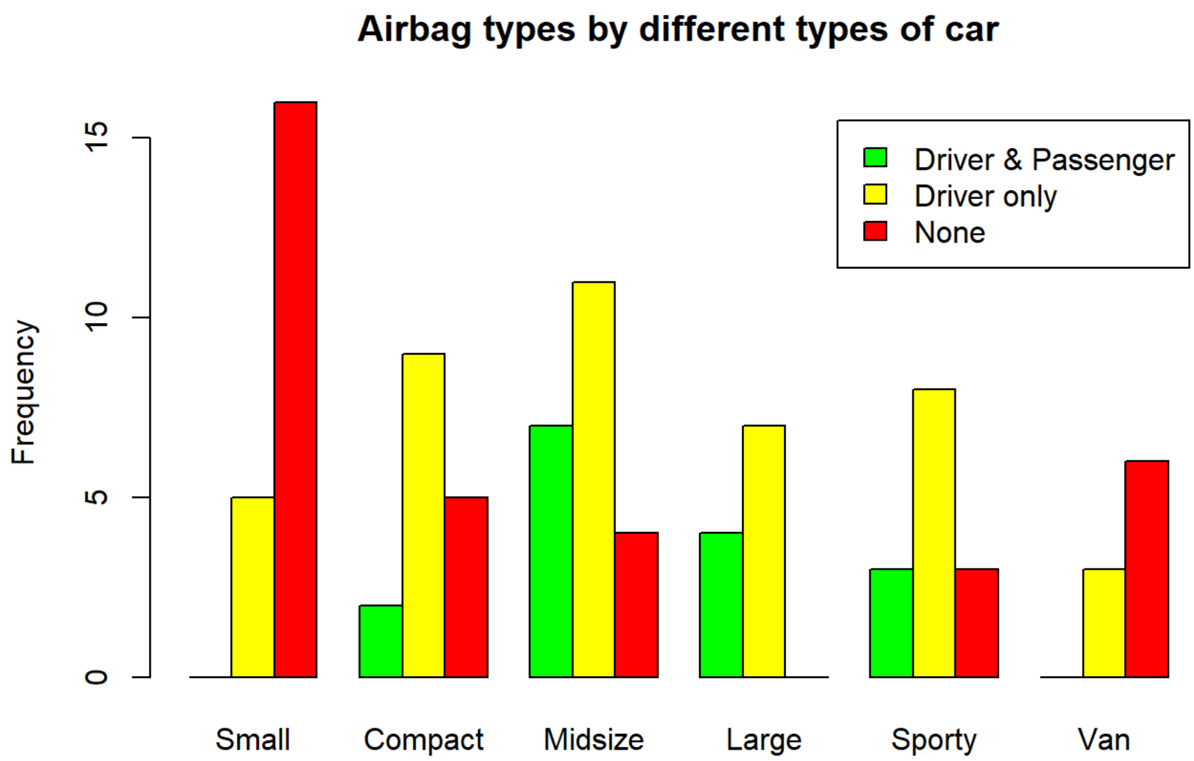
```
> barplot(table(AirBags),
+         main = "Airbags",
+         ylab = "Frequency",
+         col = c("Green", "Yellow", "Red"))
```



```
> barplot(table(Type, AirBags),
+         main = "Types of cars by different airbag
types",
+         beside = TRUE,
+         ylab = "Frequency",
+         col = brewer.pal(n = 6, name = "Blues"),
+         legend.text = TRUE)
```



```
> barplot(table(AirBags, Type),
+         main = "Airbag types by different types of
car",
+         beside = TRUE,
+         ylab = "Frequency",
+         col = c("Green", "Yellow", "Red"),
+         legend.text = TRUE)
```

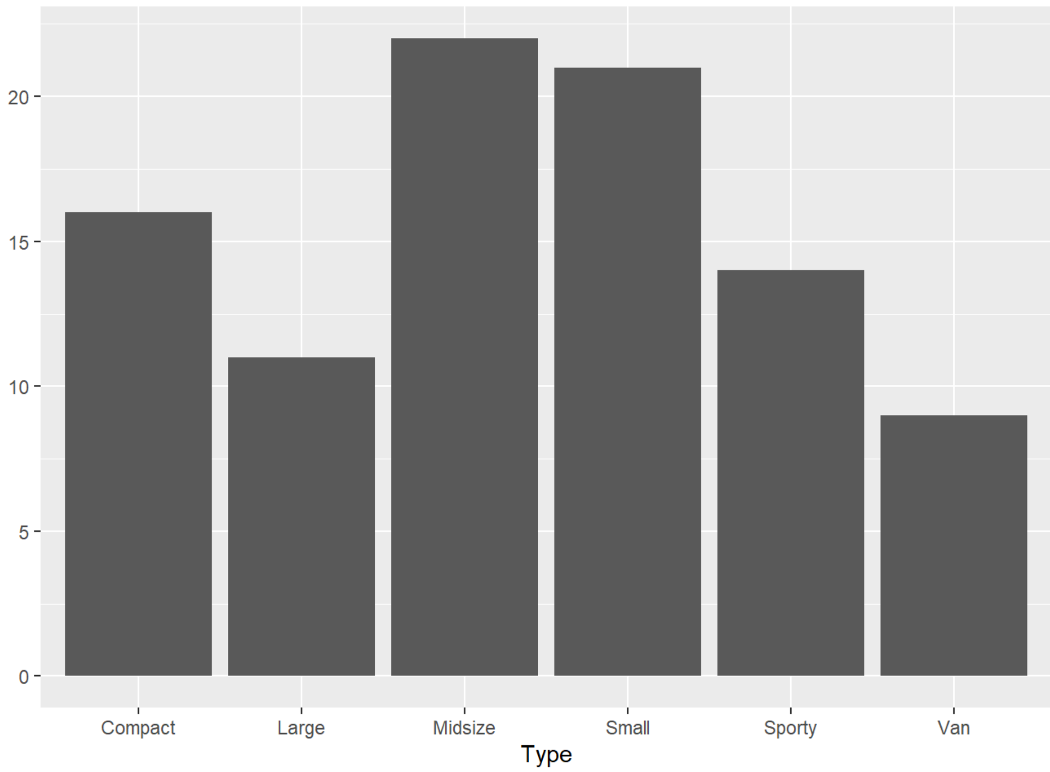


We can also use the `ggplot2` package for creating graphs

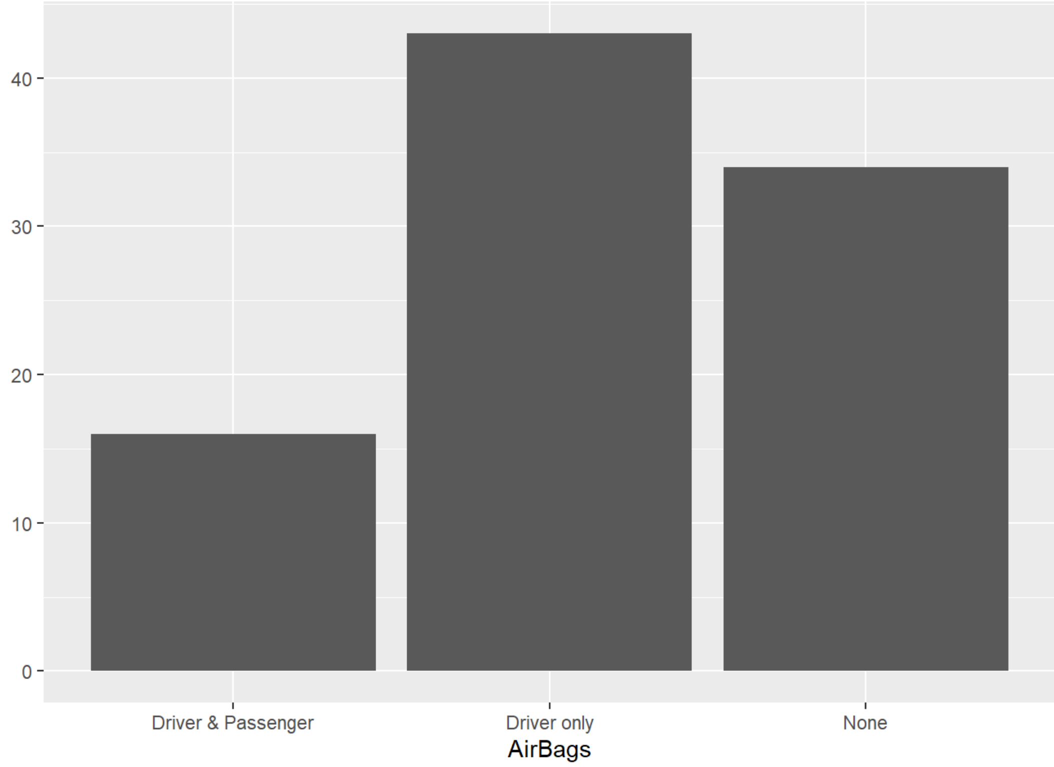
```
> install.packages("ggplot2")
> ? ggplot2
```

We will start by reviewing the quick plot `qplot` function and `ggplot` function

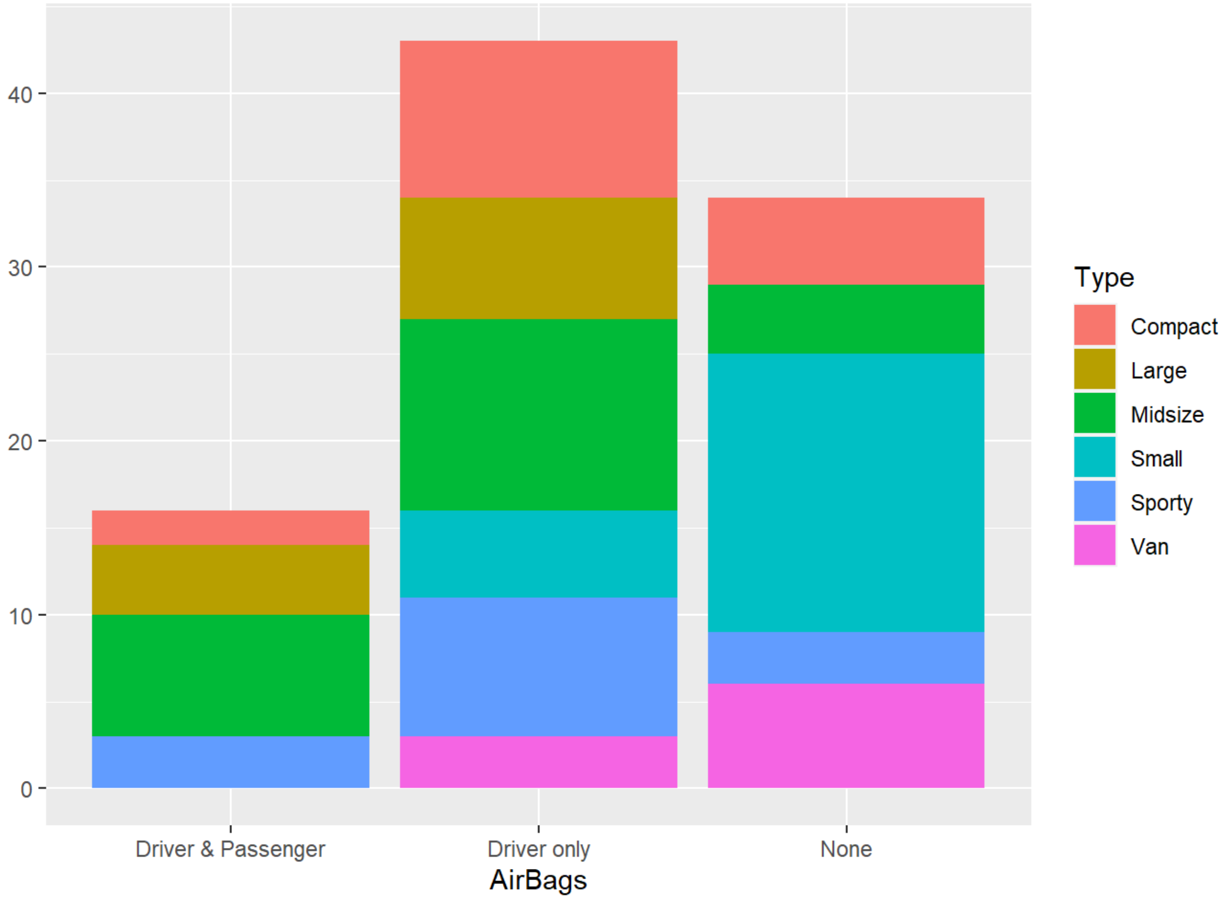
```
> library(ggplot2)
> qplot(Type, data = Cars93)
```



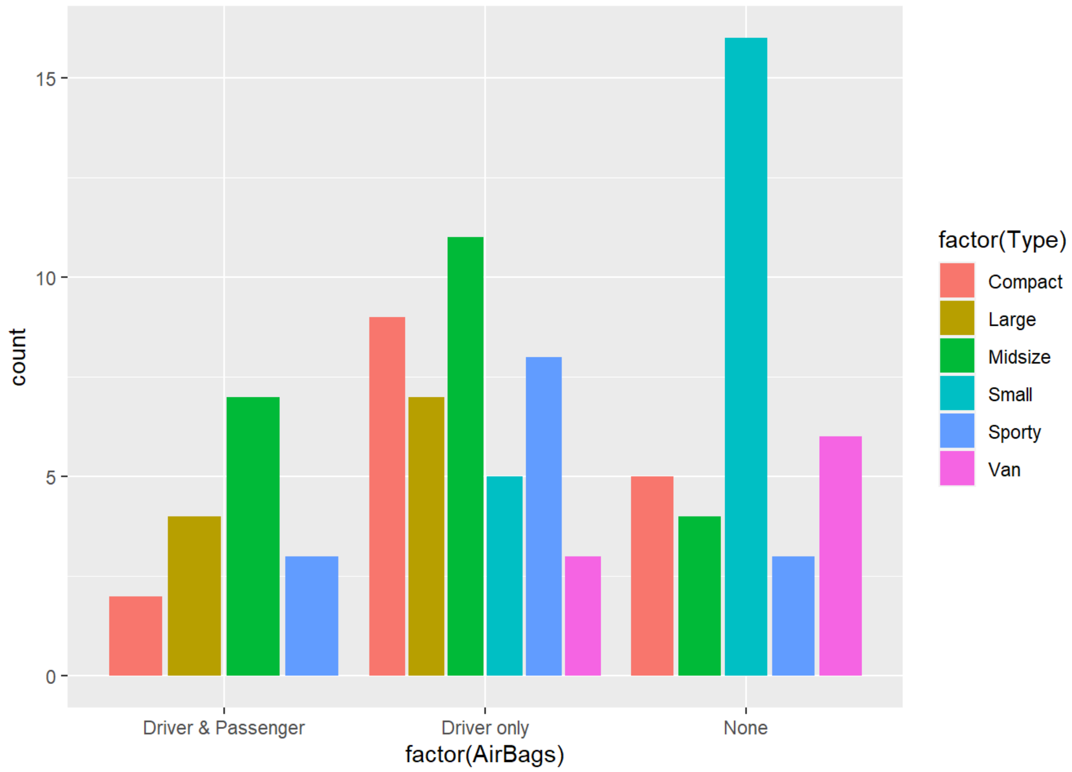
```
> qplot(AirBags, data = Cars93)
```



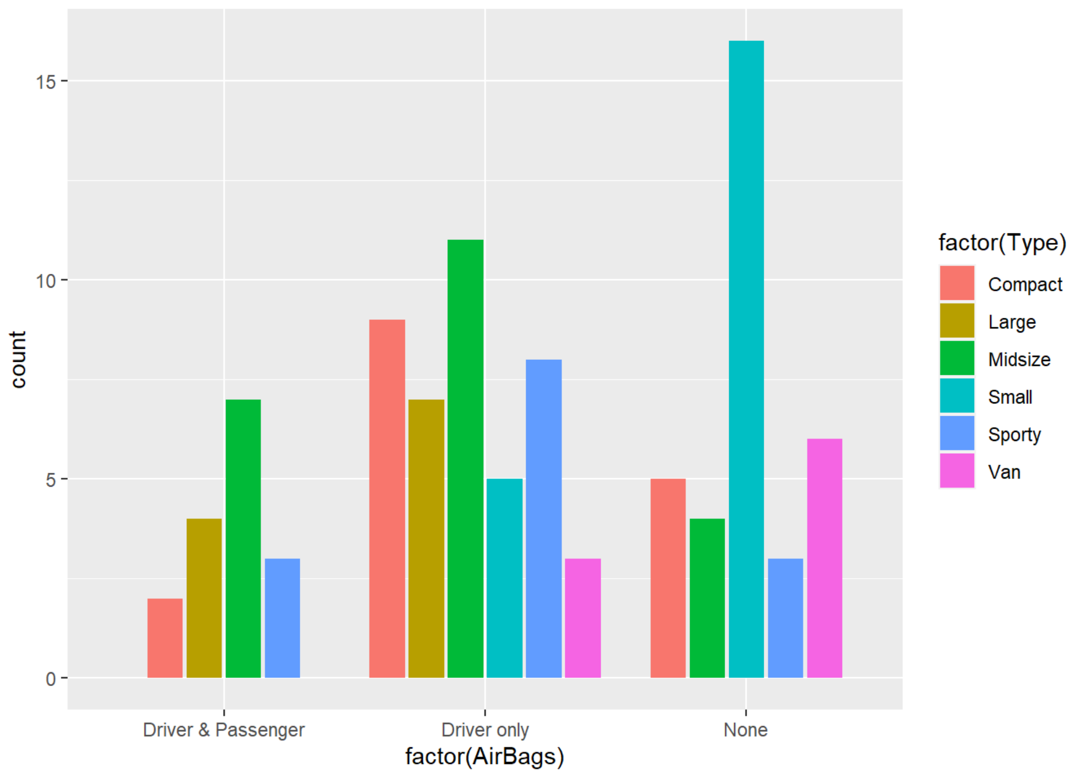

```
> qplot(AirBags, data = Cars93, fill = Type)
```



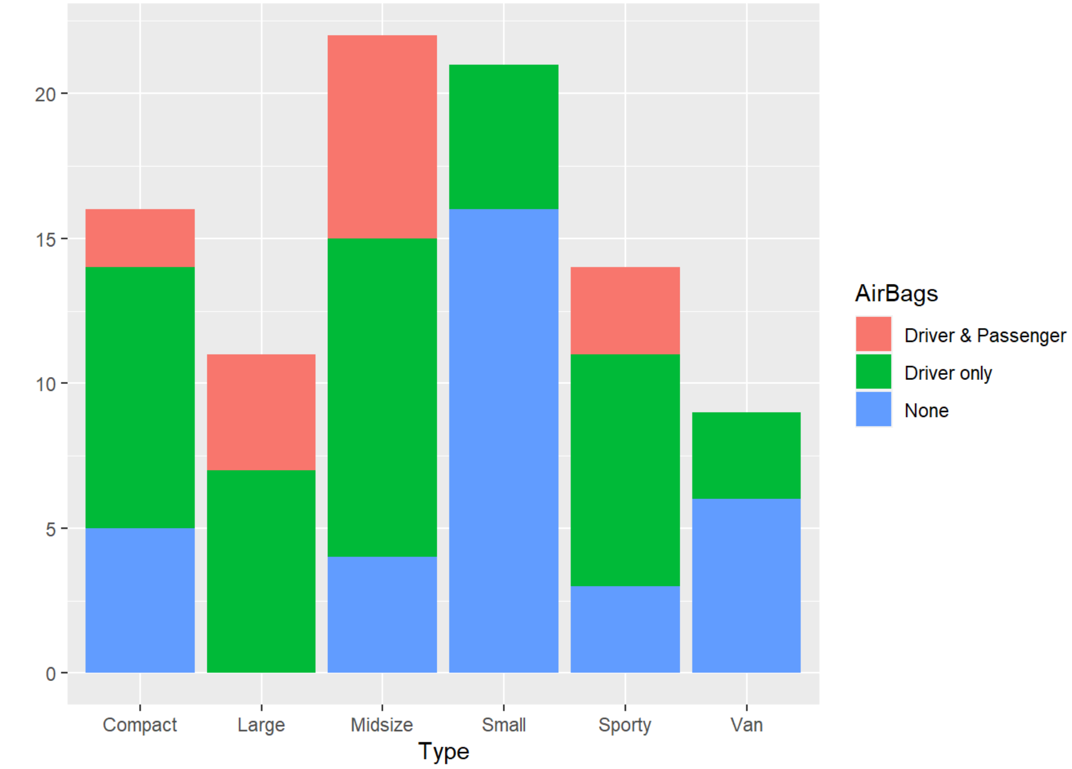
```
> ggplot(Cars93, aes(factor(AirBags), fill =
factor(Type))) +
+   geom_bar(position = "dodge2")
```



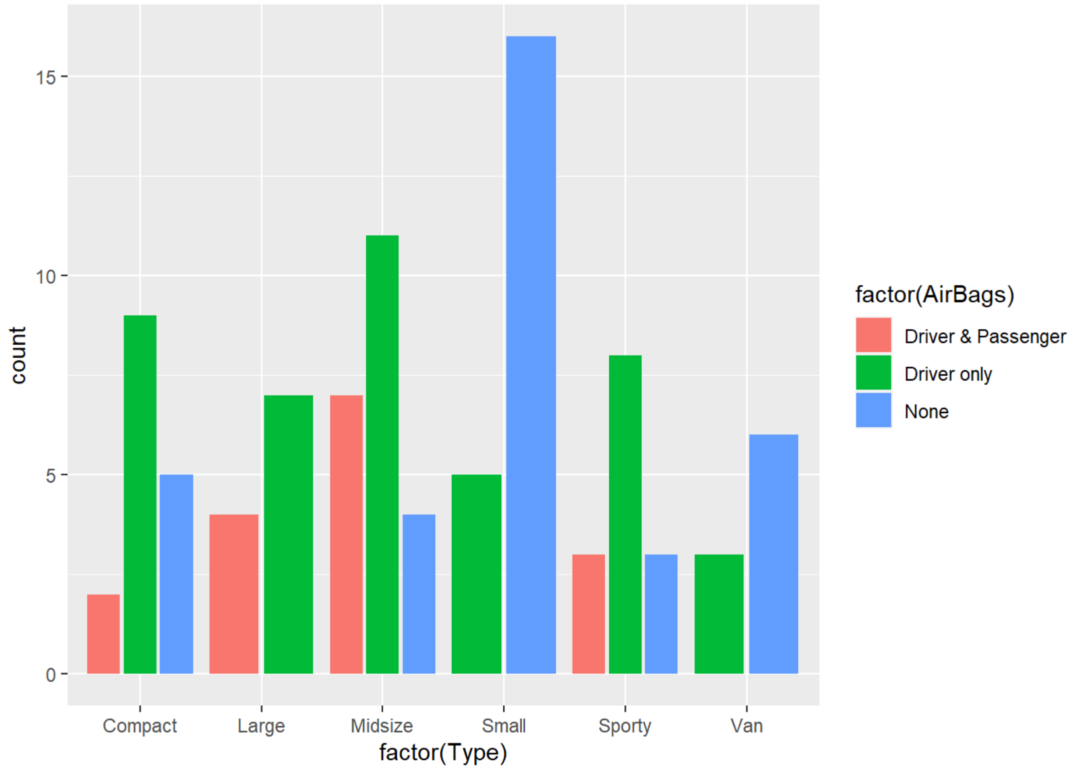

```
> ggplot(Cars93, aes(factor(AirBags), fill =
factor(Type))) +
+   geom_bar(position = position_dodge2(preserve =
"single"))
```



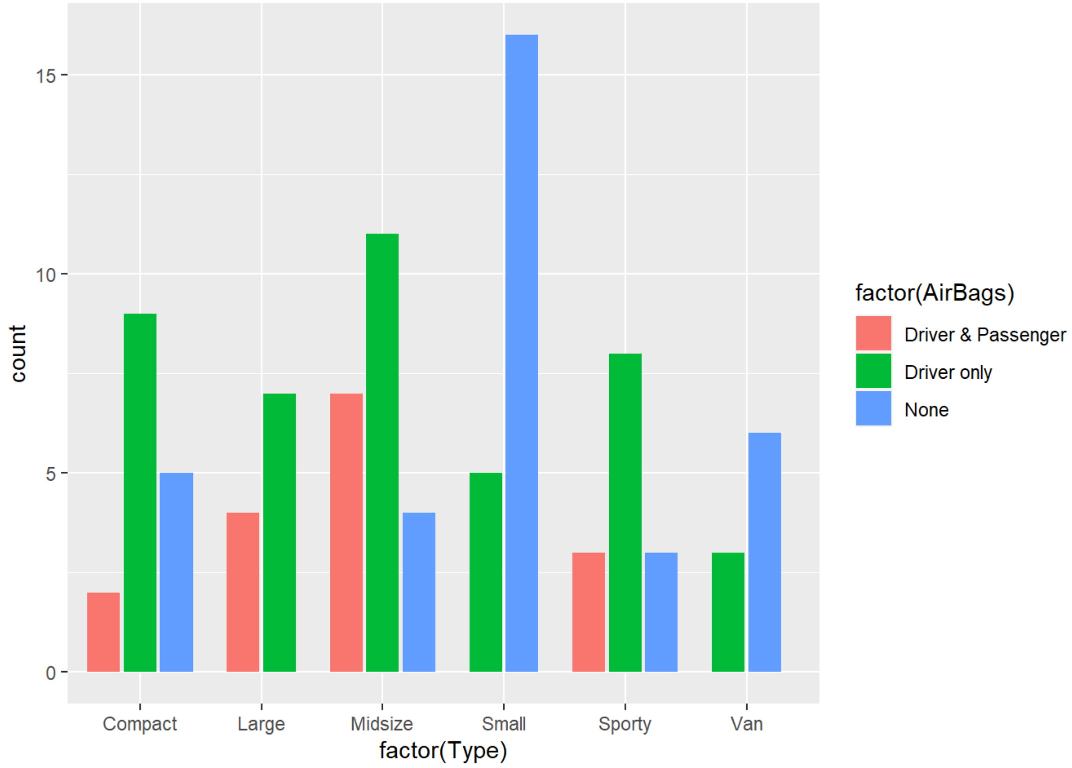
```
> qplot(Type, data = Cars93, fill = AirBags)
```




```
> ggplot(Cars93, aes(factor(Type), fill =
factor(AirBags))) +
+   geom_bar(position = "dodge2")
```



```
> ggplot(Cars93, aes(factor(Type), fill =
factor(AirBags))) +
+    geom_bar(position = position_dodge2(preserve =
"single"))
```



Another example

```
> hair <- c("blond", "blond", "black", "blond", "brown",
"brown",
+           "brown", "brown", "black", "brown", "black",
"brown",
+           "black", "black", "black", "brown", "brown",
"brown",
+           "brown", "brown", "black", "brown", "black",
"brown",
+           "blond", "blond", "black", "blond", "brown",
"brown",
+           "brown", "brown", "black", "brown", "black",
"brown",
+           "brown", "brown", "black", "brown", "black",
"brown",
+           "blond", "blond", "black", "blond", "brown",
"brown")
> eyes <- c("blue", "green", "brown",  "blue", "green",
"brown",
```

```
+            "brown", "black", "black", "green", "brown", 
"brown",
+            "green", "black", "black", "brown", "brown", 
"black",
+            "green", "black", "black", "brown", "brown", 
"black",
+            "brown",  "blue", "green", "brown", "brown", 
"black",
+            "black", "green", "brown",  "blue", "green", 
"brown",
+            "brown", "black", "brown",  "blue", "green", 
"brown",
+            "blue", "green", "brown",  "blue", "green", 
"brown")
> sex <- c("female", "male", "female", "female", 
"female", "male",
+           "male", "male", "female", "female", "male", 
"male",
+           "male", "male", "female", "male", "male", 
"female",
+           "female", "male", "female", "female", "female", 
"male",
+           "male", "male", "female", "female", "male", 
"male",
+           "male", "male", "female", "male", "male", 
"female",
+           "female", "male", "female", "female", "female", 
"male",
+           "male", "male", "female", "female", "male", 
"male")
> student <- c("yes", "no", "no", "no", "no", "yes",
+               "yes", "no", "yes", "no", "yes", "no",
+               "no", "yes", "yes", "yes", "no", "yes",
+               "yes", "no", "no", "no", "no", "yes",
+               "yes", "no", "yes", "no", "yes", "no",
+               "no", "yes", "yes", "yes", "no", "yes",
+               "yes", "no", "no", "no", "no", "yes",
+               "yes", "no", "yes", "no", "yes", "no")
> table(hair, eyes, sex, student)
, , sex = female, student = no

     eyes
```

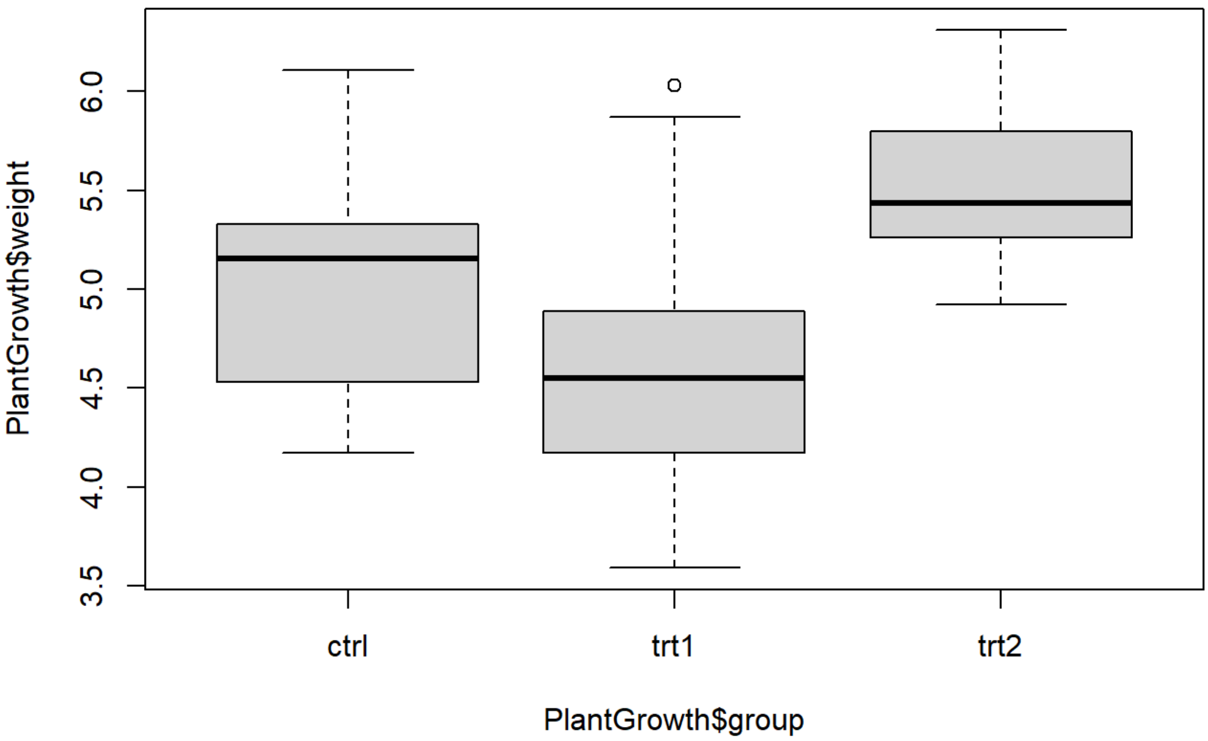
```
hair    black blue brown green
  black     1    0     3     1
  blond     0    2     1     0
  brown     0    1     1     2

, , sex = male, student = no

       eyes
hair    black blue brown green
  black     0    0     0     2
  blond     0    1     0     2
  brown     5    0     3     0

, , sex = female, student = yes

       eyes
hair    black blue brown green
  black     2    0     2     1
  blond     0    1     0     0
  brown     1    0     2     1

, , sex = male, student = yes

       eyes
hair    black blue brown green
  black     1    0     1     0
  blond     0    1     1     0
  brown     1    1     5     2
> ftable(hair, eyes, sex, student)
                   student no yes
hair  eyes  sex
black black female         1   2
            male           0   1
      blue  female         0   0
            male           0   0
      brown female         3   2
            male           0   1
      green female         1   1
            male           2   0
blond black female         0   0
            male           0   0
      blue  female         2   1
```

```
             male              1   1
      brown  female            1   0
             male              0   1
      green  female            0   0
             male              2   0
brown black  female            0   1
             male              5   1
      blue   female            1   0
             male              0   1
      brown  female            1   2
             male              3   5
      green  female            2   1
             male              0   2
> ftable(student, sex, hair, eyes)
                     eyes black blue brown green
student sex    hair
no      female black            1    0     3     1
               blond            0    2     1     0
               brown            0    1     1     2
        male   black            0    0     0     2
               blond            0    1     0     2
               brown            5    0     3     0
yes     female black            2    0     2     1
               blond            0    1     0     0
               brown            1    0     2     1
        male   black            1    0     1     0
               blond            0    1     1     0
               brown            1    1     5     2
```

Categorical and numerical data

Let's review the `PlantGrowth` data frame

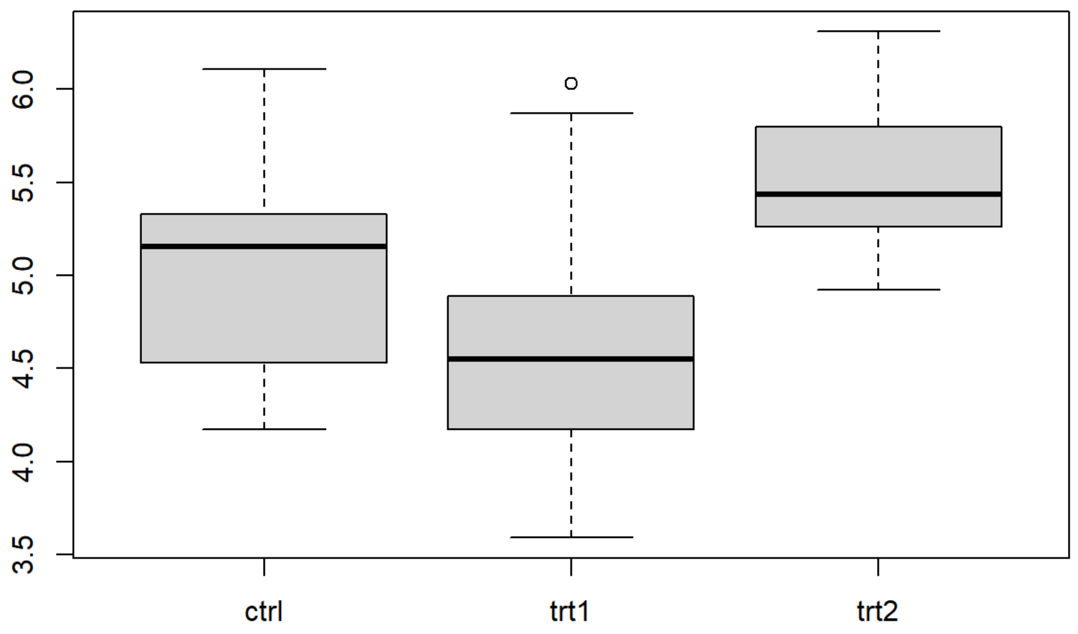
```
> head(PlantGrowth)
  weight group
1    4.2  ctrl
2    5.6  ctrl
3    5.2  ctrl
4    6.1  ctrl
5    4.5  ctrl
6    4.6  ctrl
> boxplot(PlantGrowth$weight ~ PlantGrowth$group)
```



Another way is using the `unstack` function

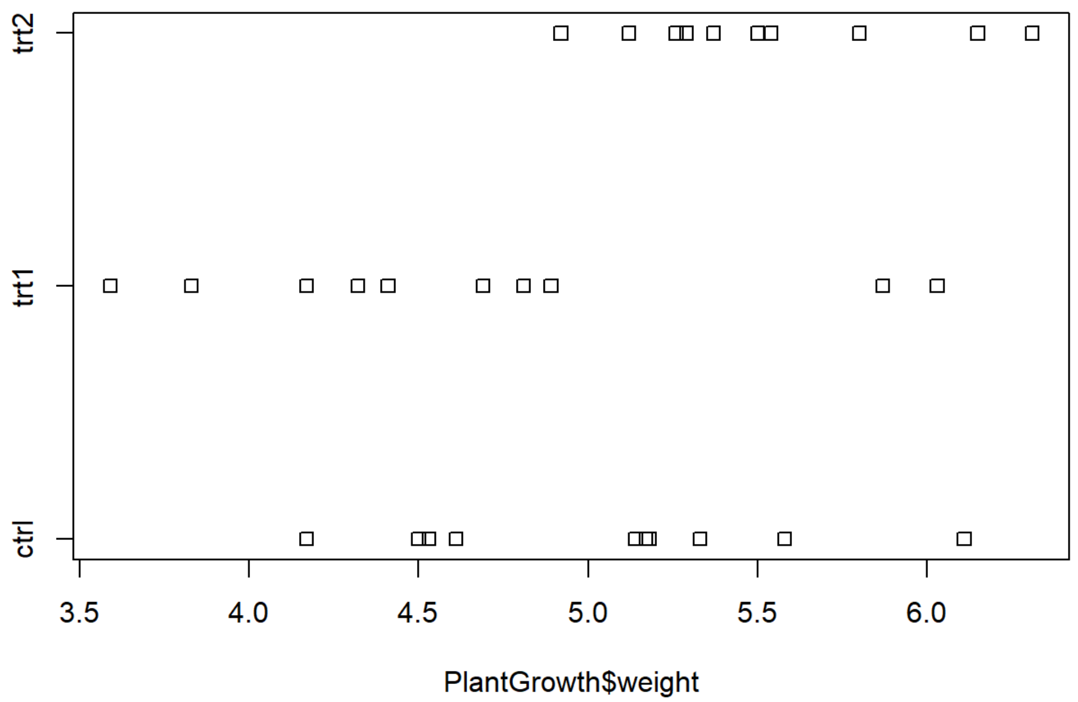
```
> unstack(PlantGrowth)
   ctrl trt1 trt2
1   4.2  4.8  6.3
2   5.6  4.2  5.1
3   5.2  4.4  5.5
4   6.1  3.6  5.5
5   4.5  5.9  5.4
6   4.6  3.8  5.3
7   5.2  6.0  4.9
8   4.5  4.9  6.2
9   5.3  4.3  5.8
10  5.1  4.7  5.3
```

```
> boxplot(unstack(PlantGrowth))
```



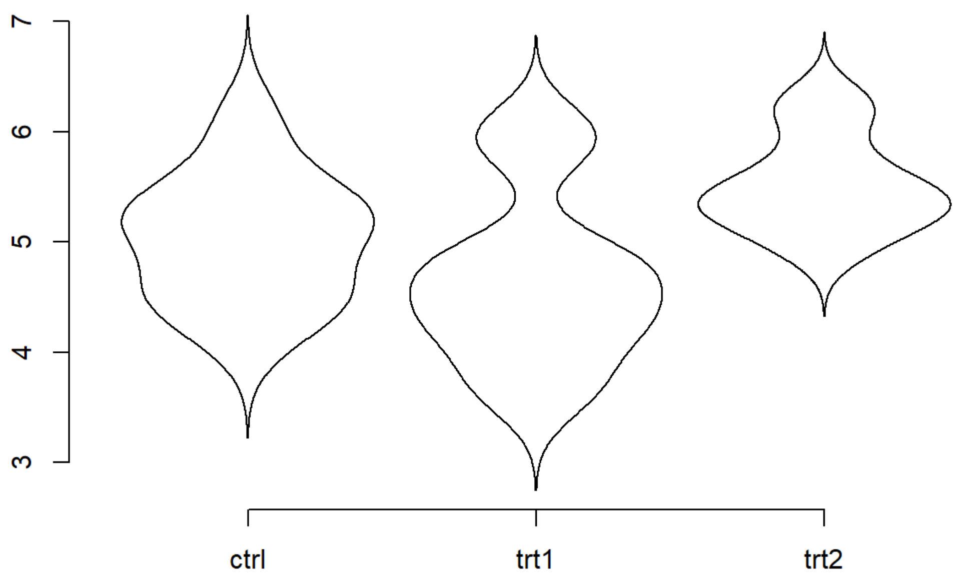
We can also visualize it using `stripchart`

```
> stripchart(PlantGrowth$weight ~ PlantGrowth$group)
```

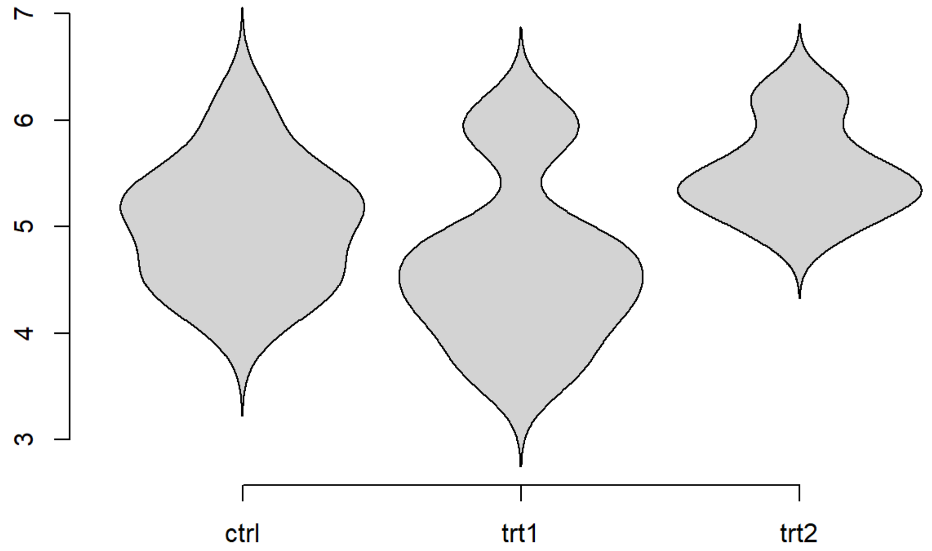


or with violinplot using the `simple.violinplot` function from `UsingR` package

```
> library(UsingR)
Warning: package 'UsingR' was built under R version 4.0.3
Loading required package: HistData
Loading required package: Hmisc
Loading required package: lattice
Loading required package: survival
Loading required package: Formula

Attaching package: 'Hmisc'
The following objects are masked from 'package:base':

    format.pval, units

Attaching package: 'UsingR'
The following object is masked from 'package:survival':

    cancer
> simple.violinplot(PlantGrowth$weight ~
PlantGrowth$group)
```

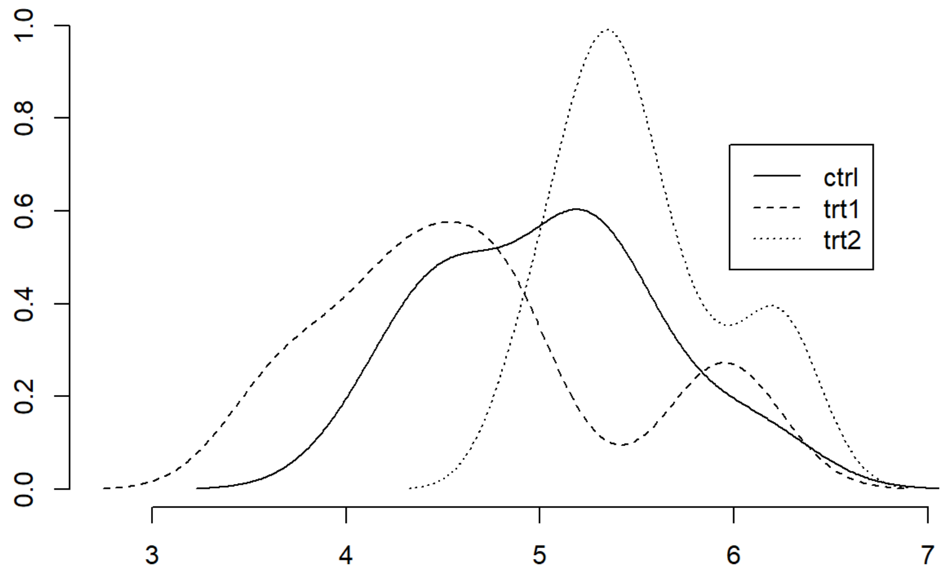


```
> simple.violinplot(PlantGrowth$weight ~
PlantGrowth$group, col = "lightgray")
```



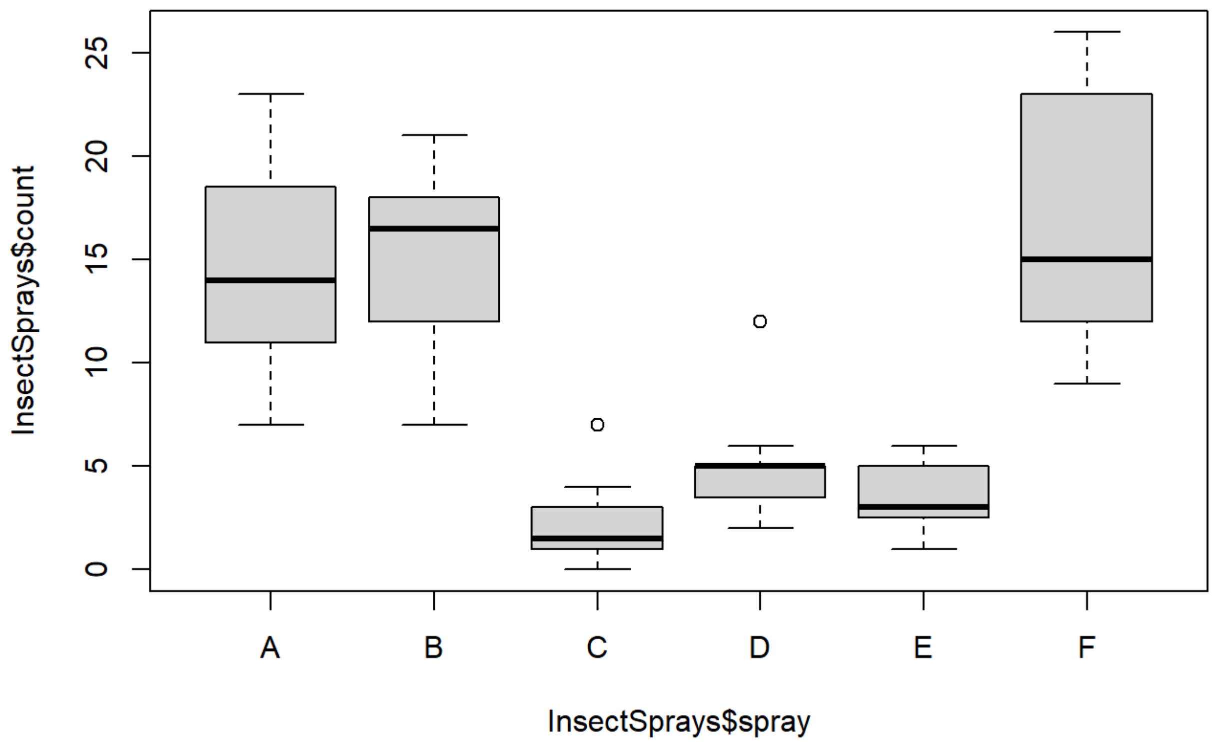
or with densities using the `simple.densityplot` function from `UsingR` package

```
> simple.densityplot(PlantGrowth$weight ~
PlantGrowth$group)
```

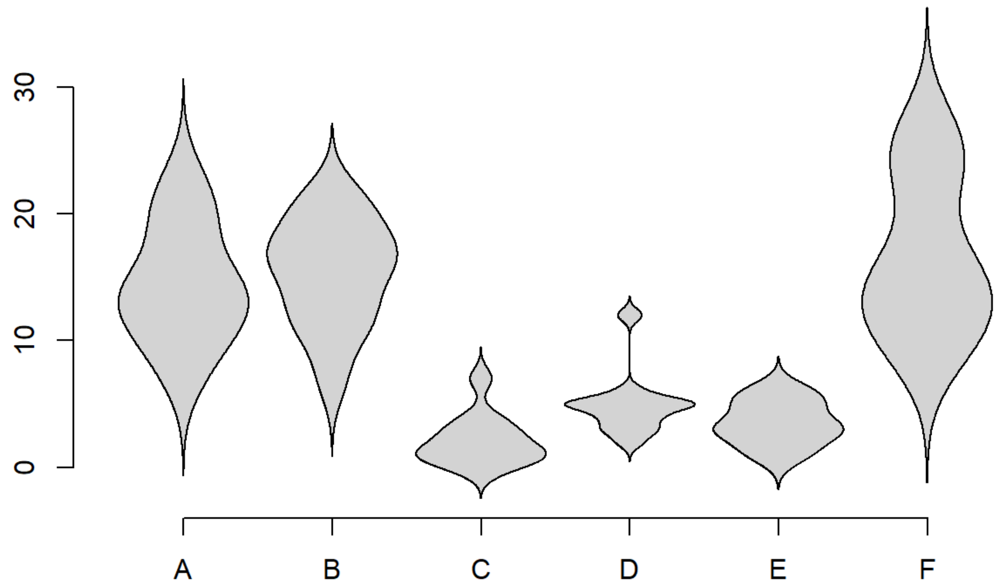


Another example. Let's review the InsectSpray's data frame presenting the counts of insects in agricultural experiment units treated with different insecticides.

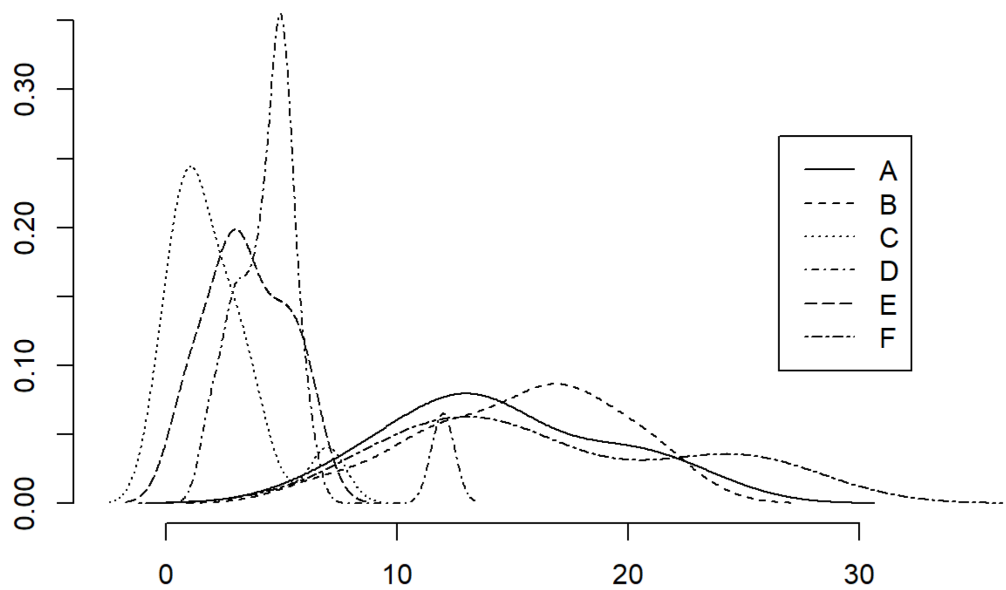
```
> head(InsectSprays)
  count spray
1    10     A
2     7     A
3    20     A
4    14     A
5    14     A
6    12     A
> boxplot(InsectSprays$count ~ InsectSprays$spray)
```



```
> simple.violinplot(InsectSprays$count ~
InsectSprays$spray, col = "lightgray")
```




```
> simple.densityplot(InsectSprays$count ~
InsectSprays$spray)
```

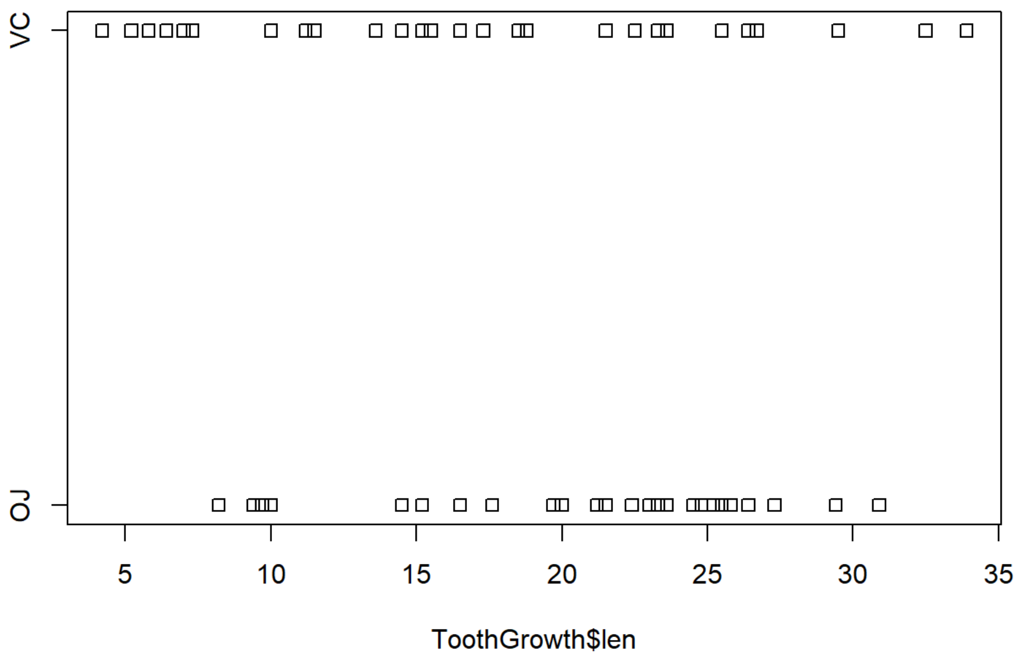


One more example with `ToothGrowth` data frame presenting the effect of vitamin C on tooth growth in guinea pigs. Here we have 1 numerical and 2 categorical variables.

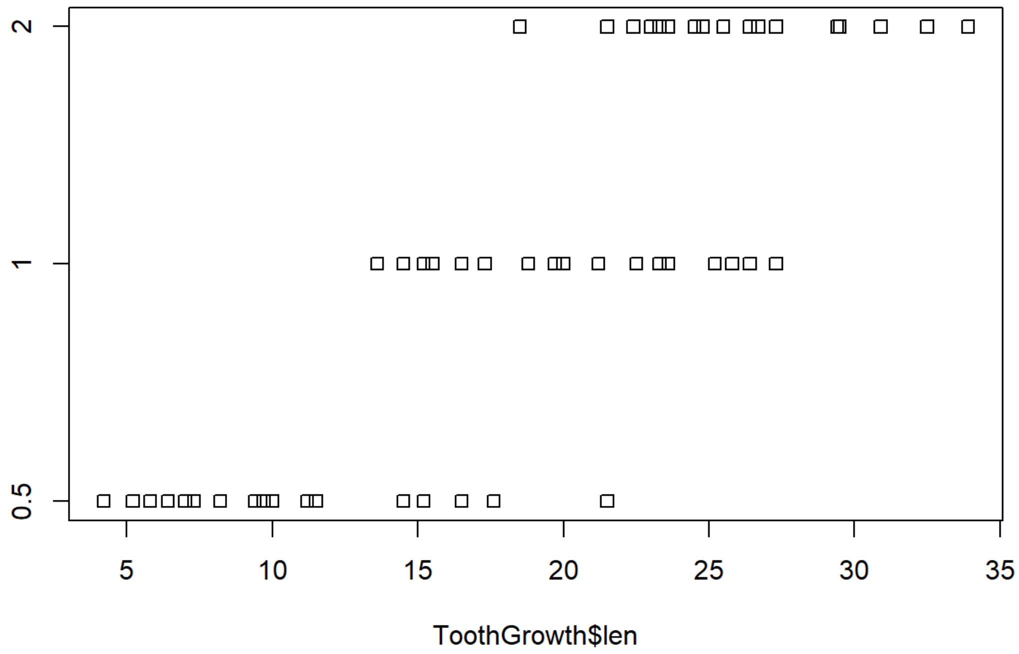
```
> head(ToothGrowth)
   len supp dose
1  4.2   VC  0.5
2 11.5   VC  0.5
3  7.3   VC  0.5
4  5.8   VC  0.5
5  6.4   VC  0.5
6 10.0   VC  0.5
```

We can use `stripchart` to show the effect of each of the categorical variables.

```
> stripchart(ToothGrowth$len ~ ToothGrowth$supp)
```

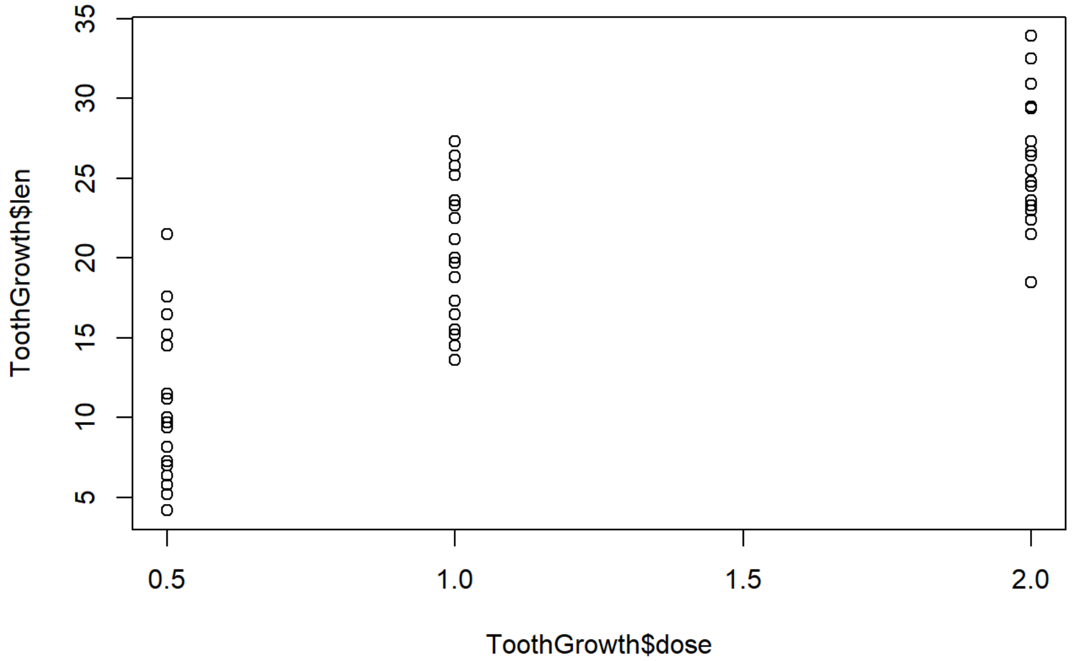


```
> stripchart(ToothGrowth$len ~ ToothGrowth$dose)
```



But how can we show the effect of both categorical variables on one graph?

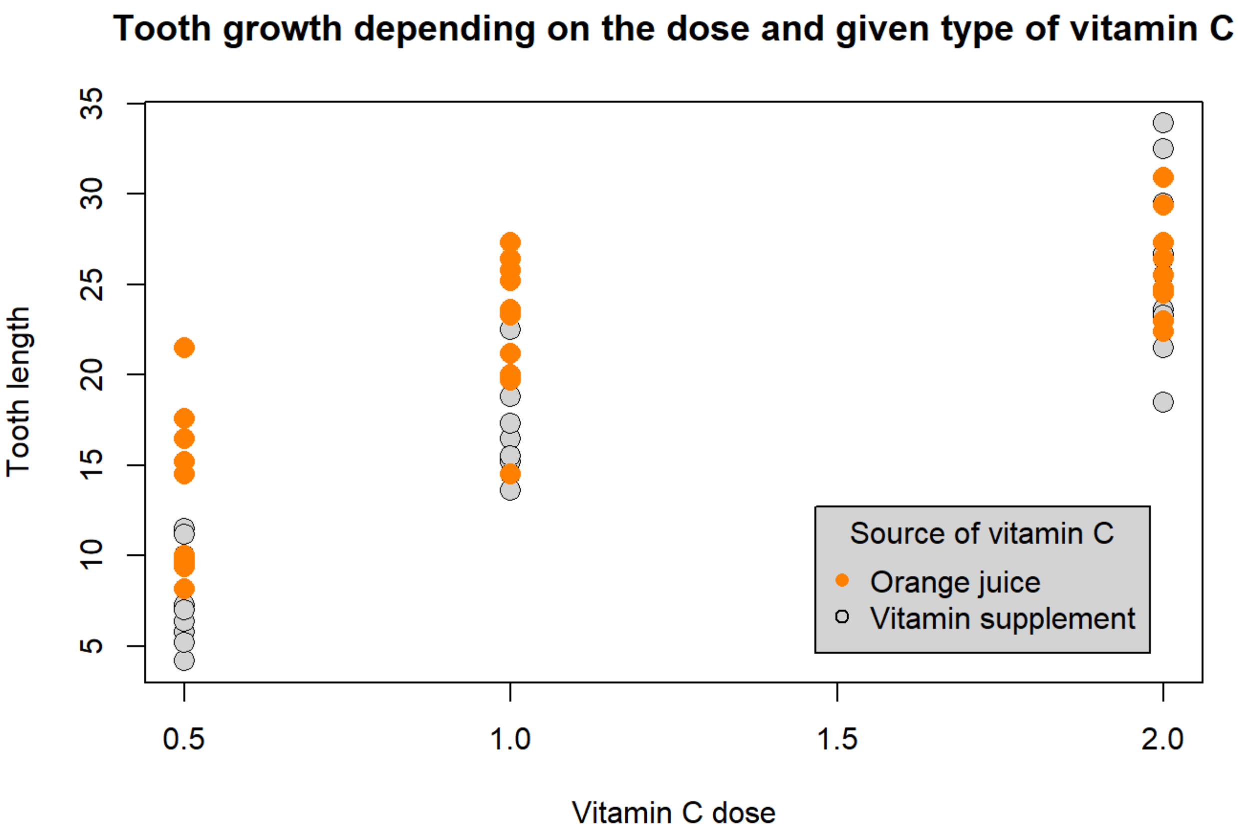
```
> plot(ToothGrowth$len ~ ToothGrowth$dose)
```



We can plot the other categorical variable on the above plot using different signs or colors marking the observations.

We can use the `pch` and `col` parameters in `plot` function to specify the point symbols and colors.

```
> colors <- c("darkorange1", "black")
> shapes <- c(16, 21)
> plot(ToothGrowth$len ~ ToothGrowth$dose,
+       main = "Tooth growth depending on the dose and 
given type of vitamin C",
+       xlab = "Vitamin C dose",
+       ylab = "Tooth length",
+       col = colors[ToothGrowth$supp],
+       bg = "lightgray",
+       pch = shapes[ToothGrowth$supp],
+       lwd = 0.9,
+       cex = 1.5)
> legend("bottomright", inset = 0.05,
+         title="Source of vitamin C",
+         legend = c("Orange juice", "Vitamin 
supplement"),
+         col = colors,
+         bg = "lightgray",
+         pch = shapes)
```



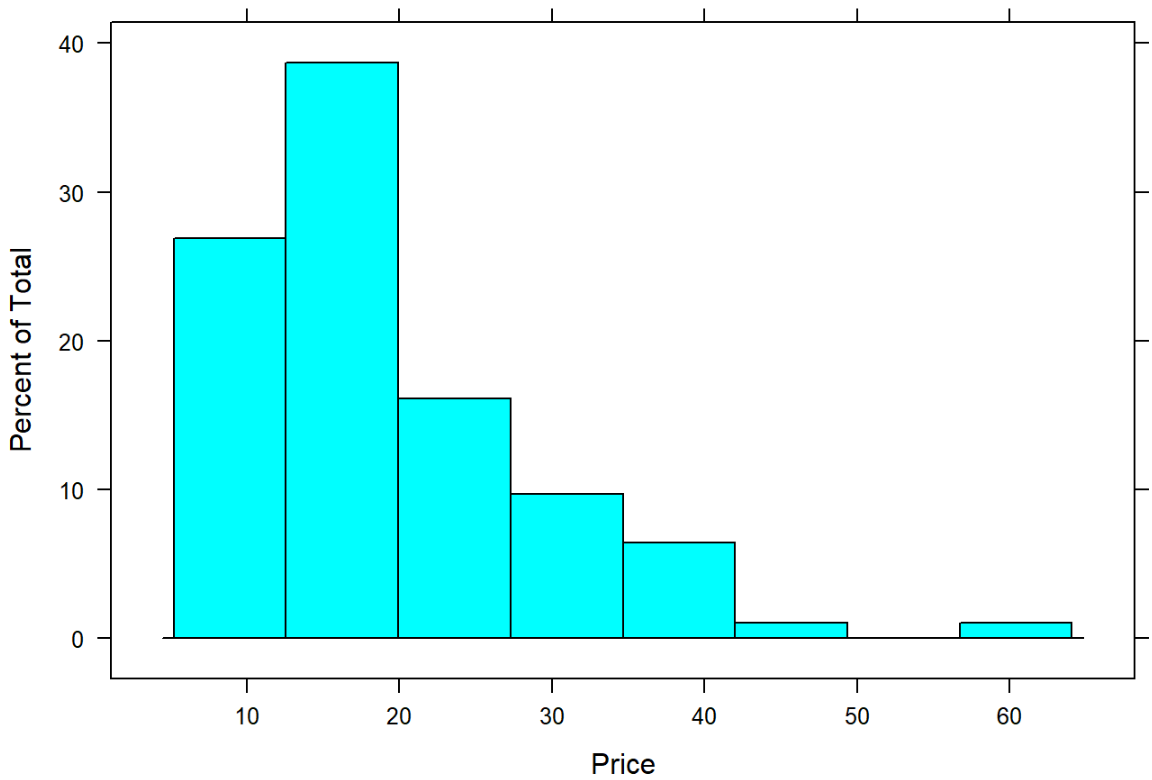
We see that in the groups taking 0.5 mg and 1.0 mg doses, the orange juice source was more effective on the tooth growth.

`lattice` is another useful package for easily displaing multivariate graphics.

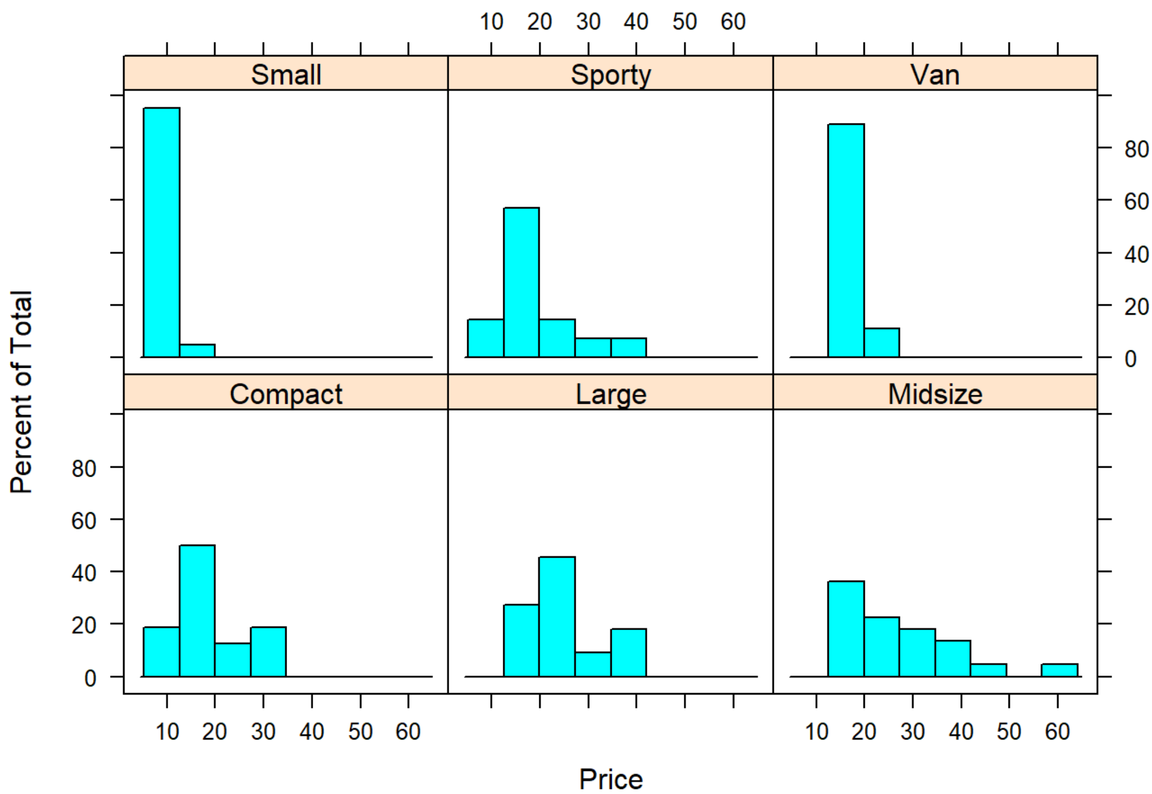
```
> install.packages("lattice")
> ? lattice
> library(lattice)
```

Continuing the `Cars93` example we can make a histogram for the `Price` depending on the `Type` of the car

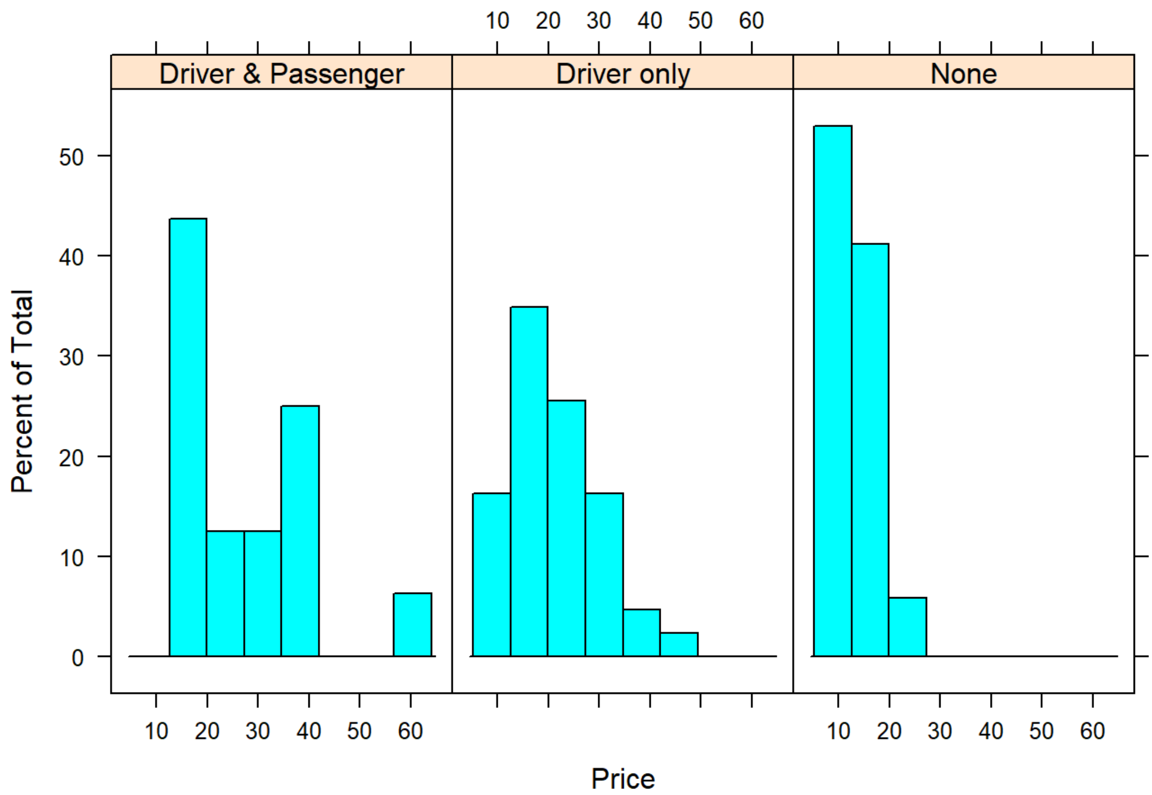
```
> histogram( ~ Price, data = Cars93)
```



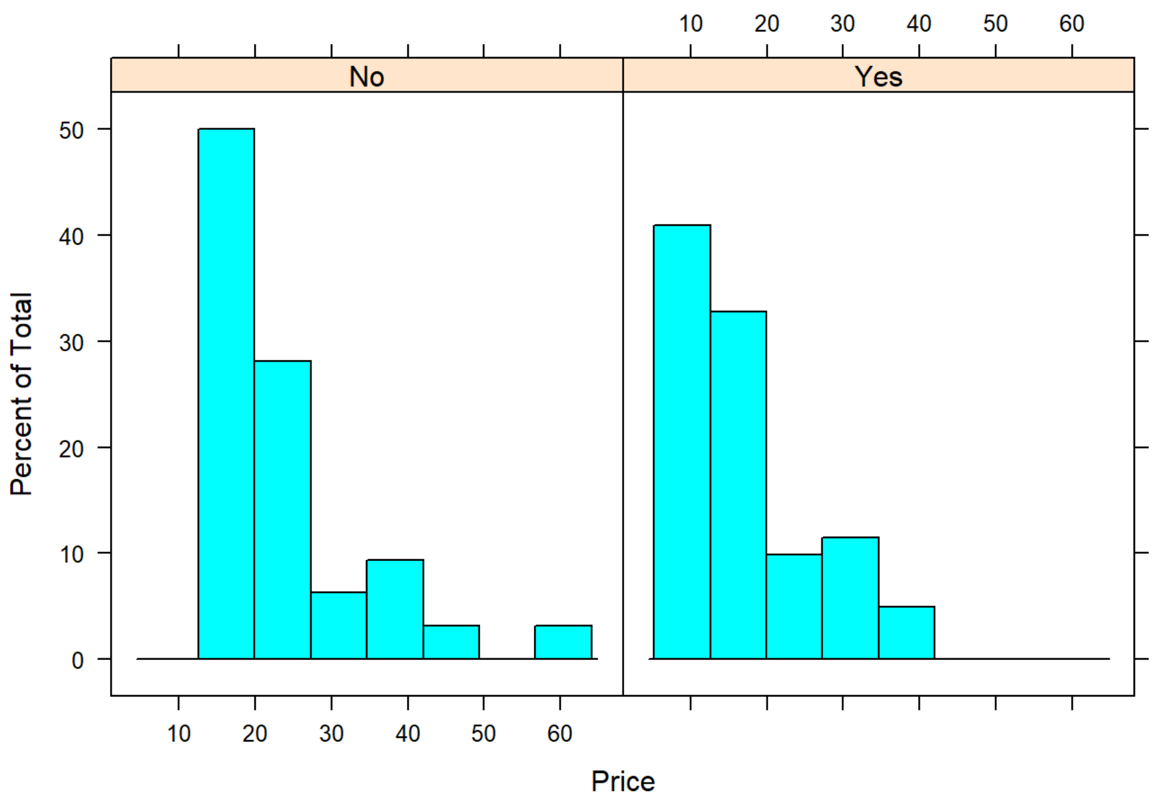

```
> histogram( ~ Price | Type, data = Cars93)
```



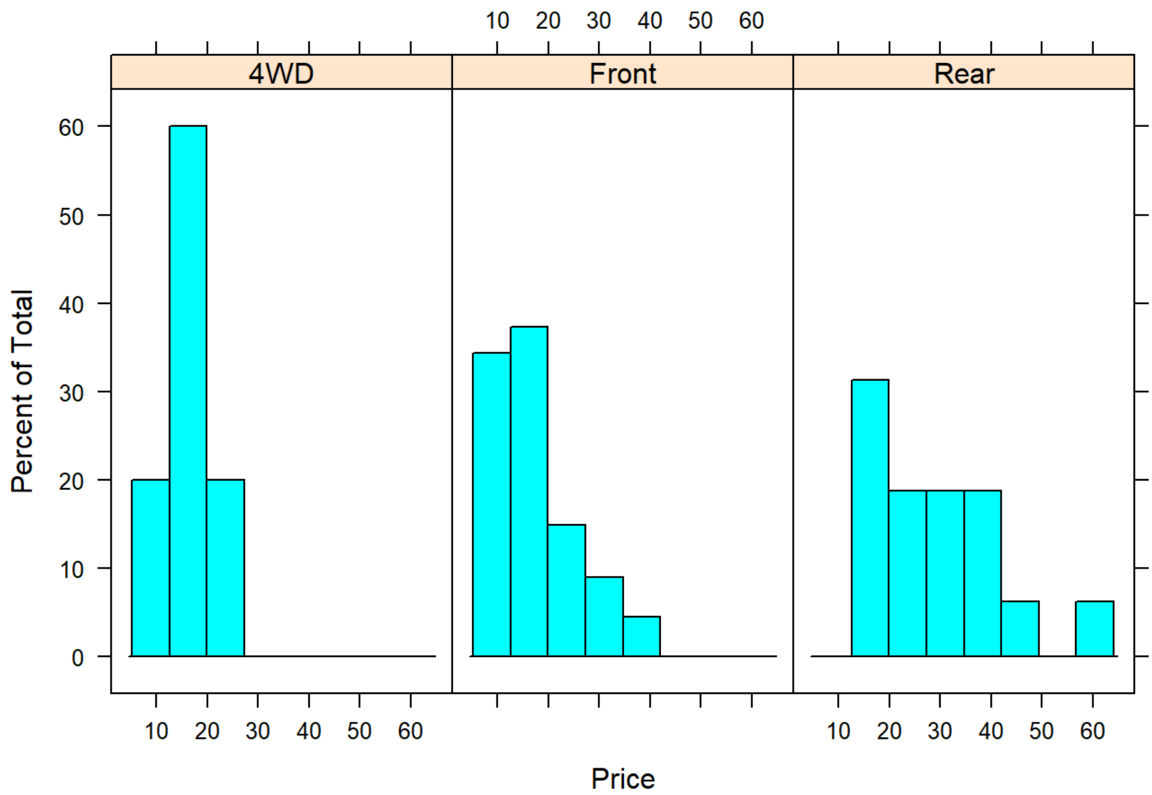
```
> histogram( ~ Price | AirBags, data = Cars93)
```



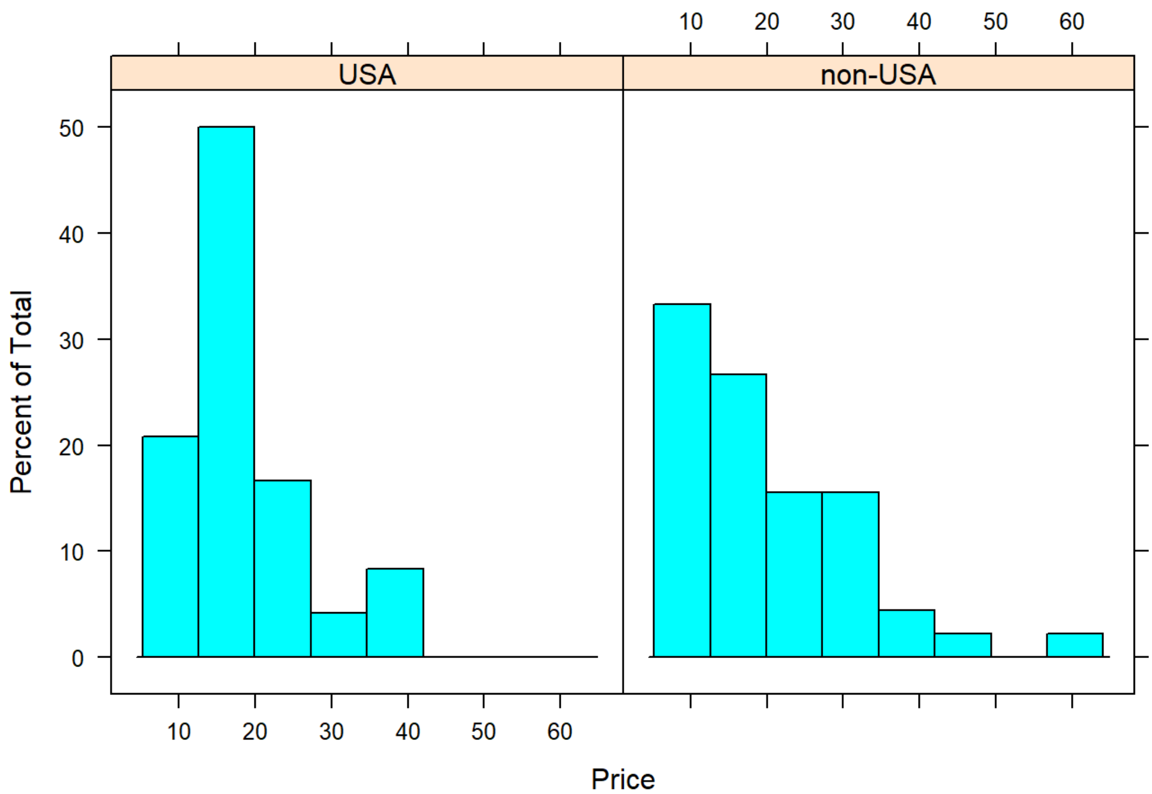

```
> histogram( ~ Price | Man.trans.avail, data = Cars93)
```



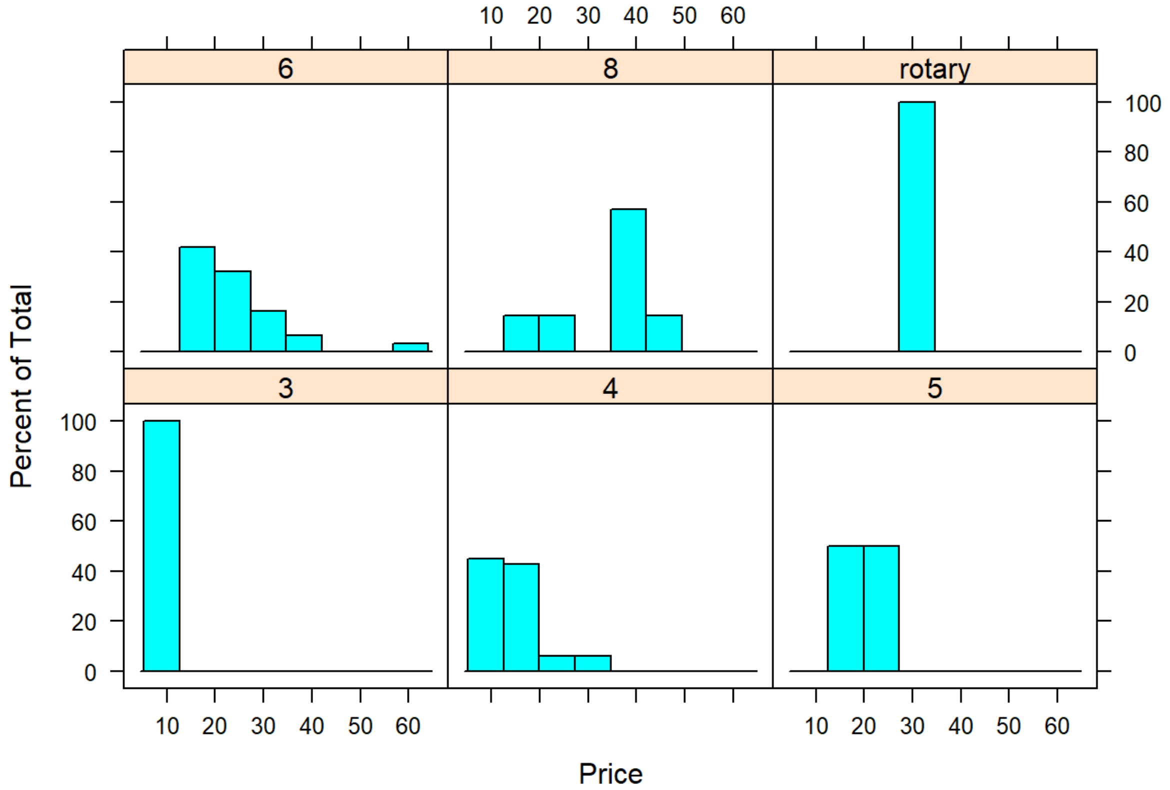
```
> histogram( ~ Price | DriveTrain, data = Cars93)
```



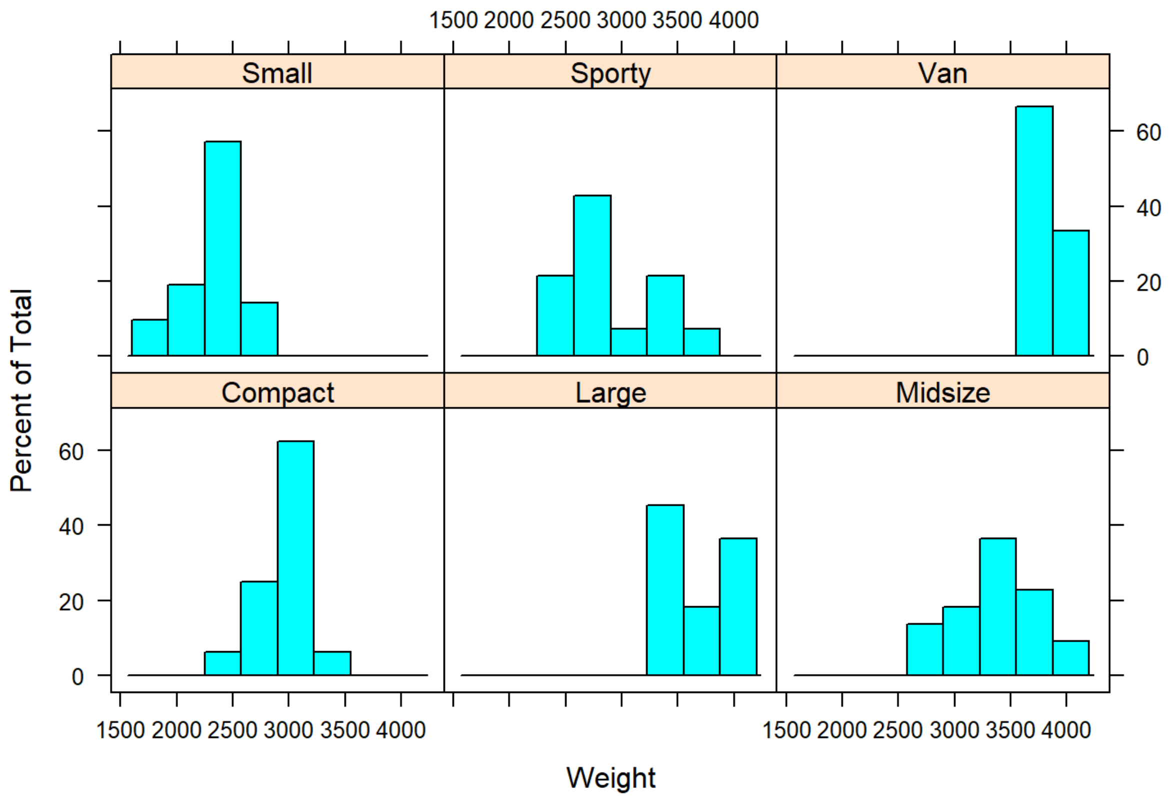

```
> histogram( ~ Price | Origin, data = Cars93)
```



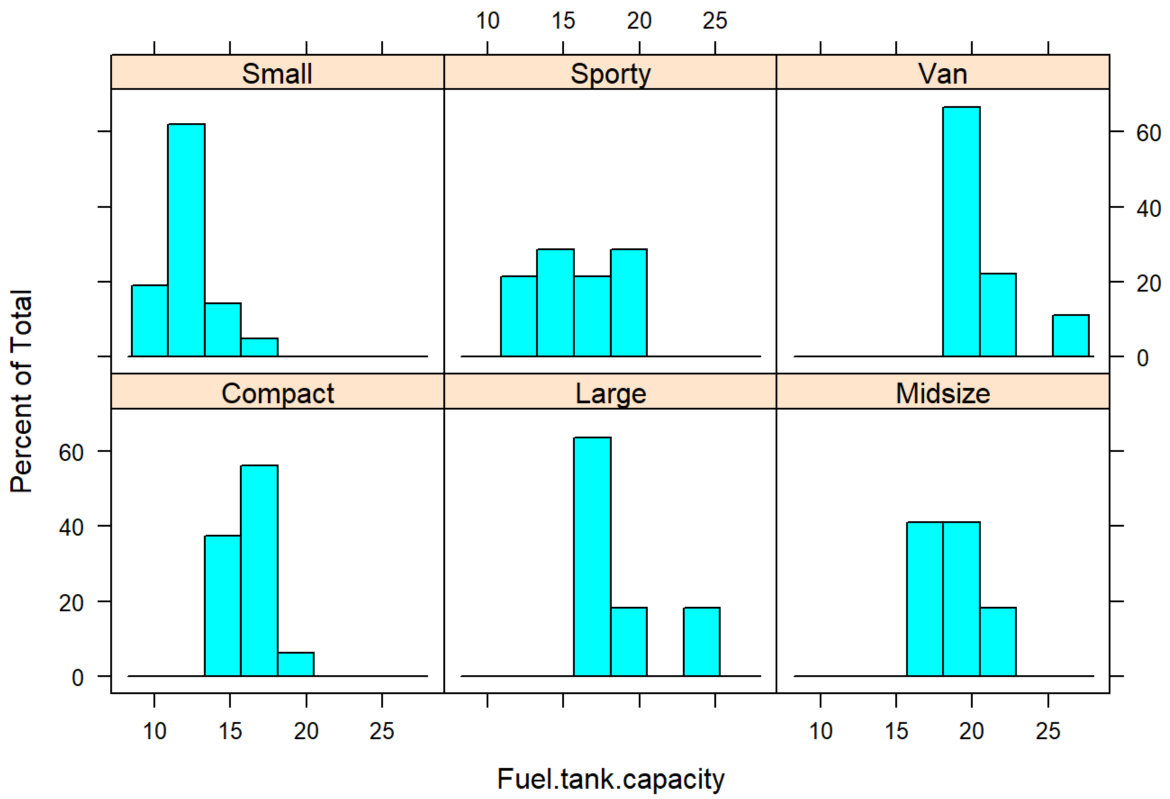
```
> histogram( ~ Price | Cylinders , data = Cars93)
```



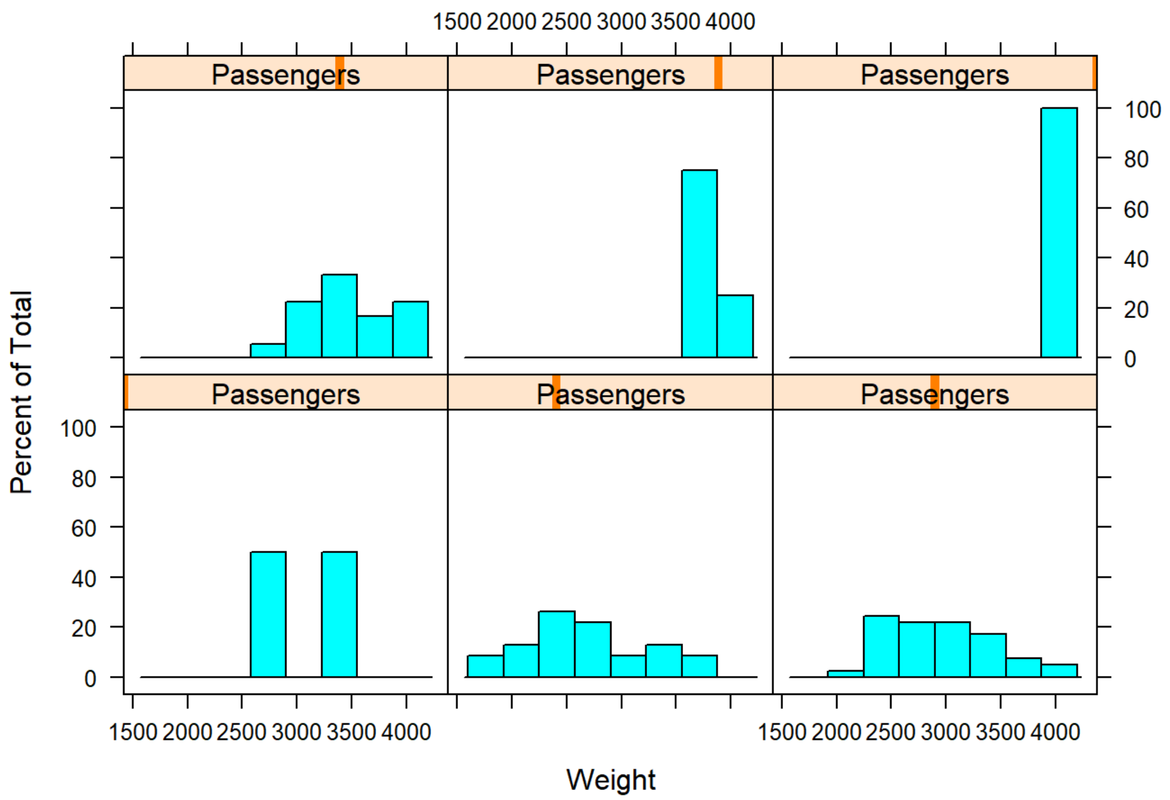

```
> histogram( ~ Weight | Type , data = Cars93)
```



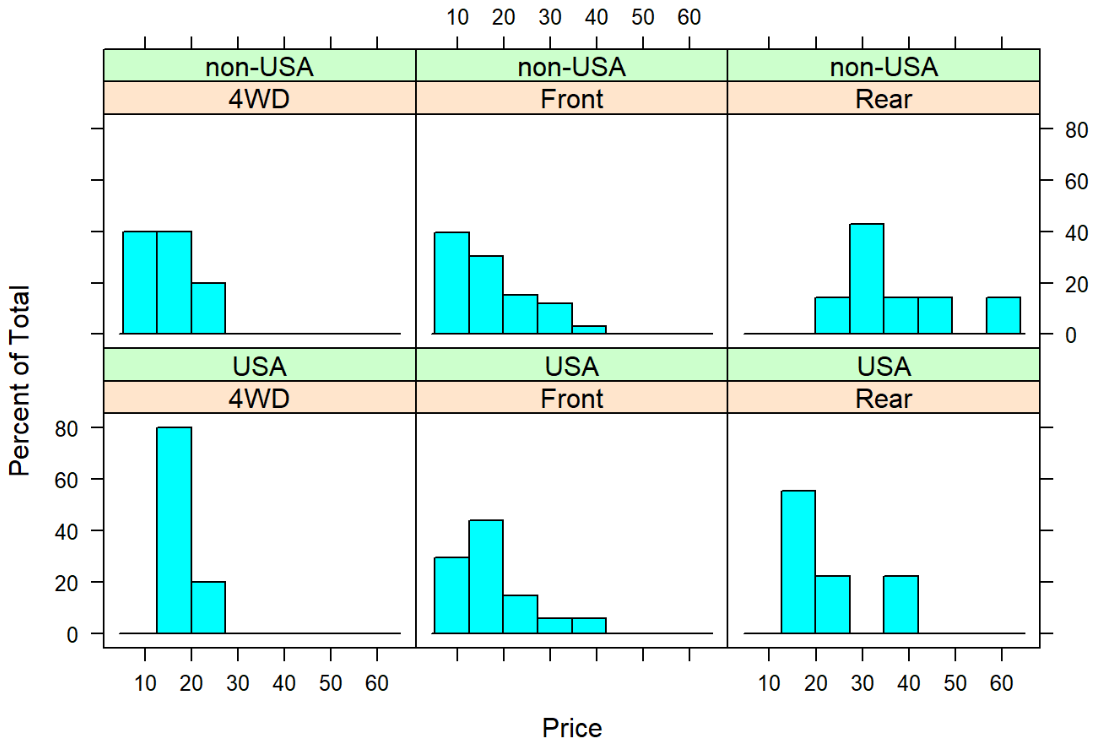
```
> histogram( ~ Fuel.tank.capacity | Type , data = Cars93)
```




```
> histogram( ~ Weight | Passengers , data = Cars93)
```

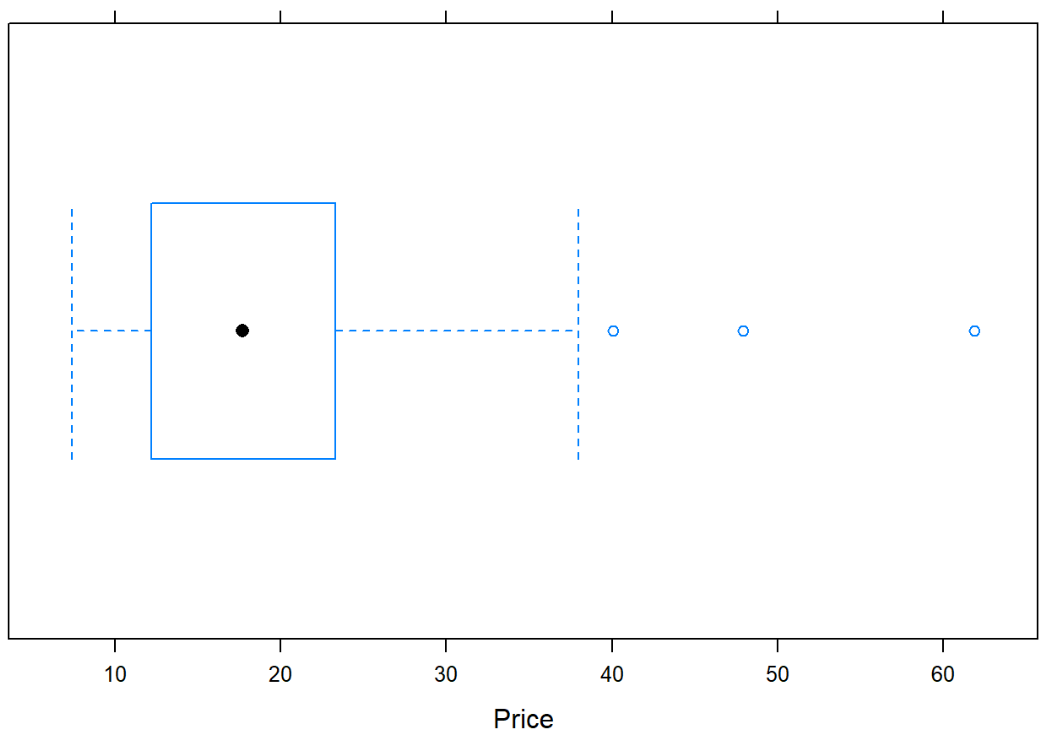


```
> histogram( ~ Price | DriveTrain * Origin, data =
Cars93)
```

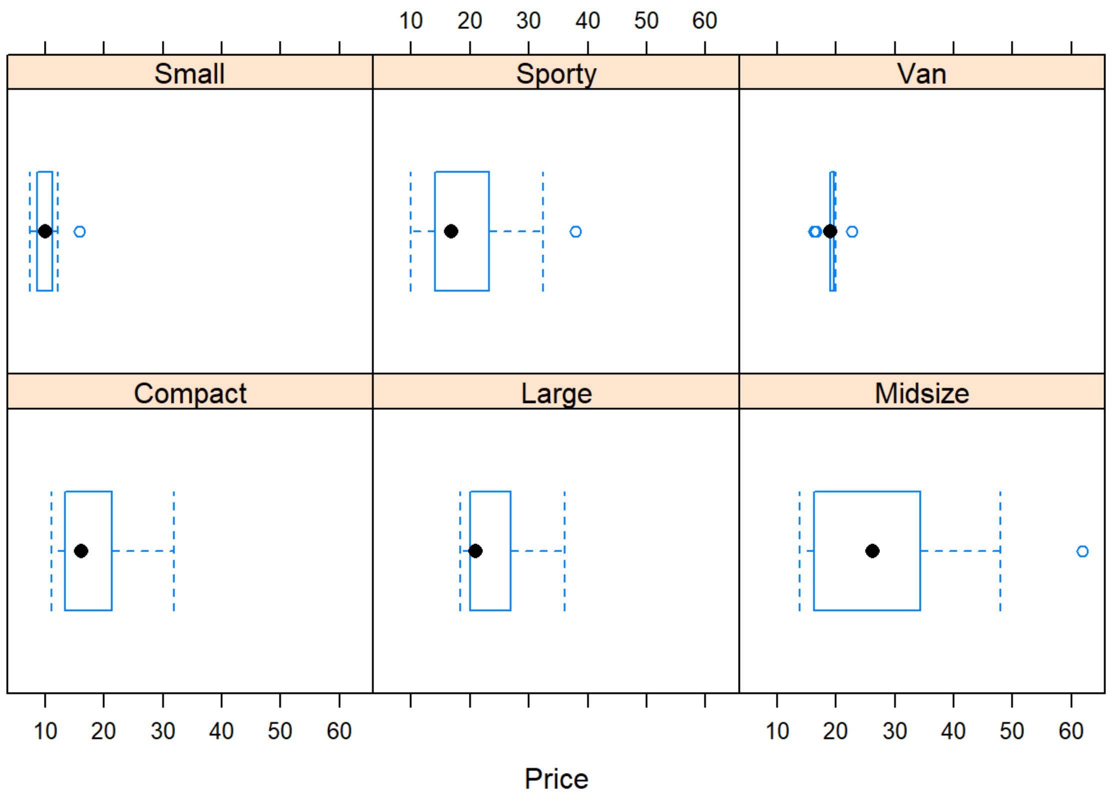


We can similarly make the boxplot lattice graphics using the `bwplot` function

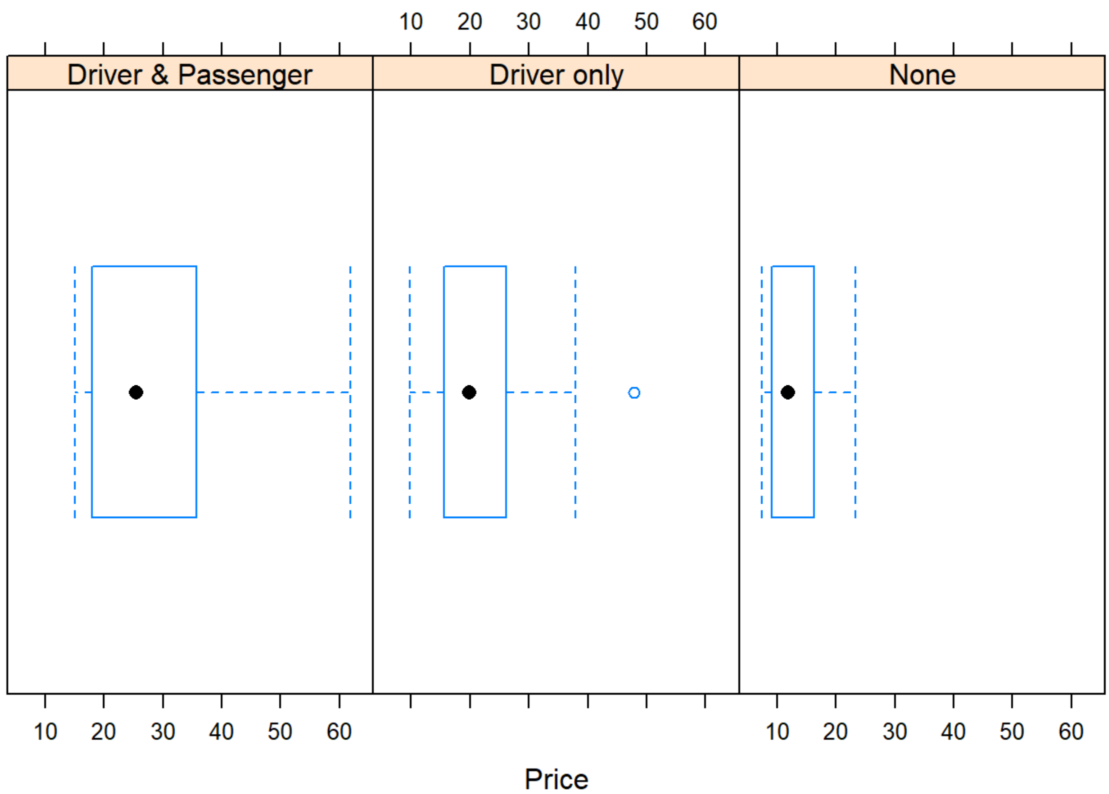
```
> bwplot( ~ Price, data = Cars93)
```



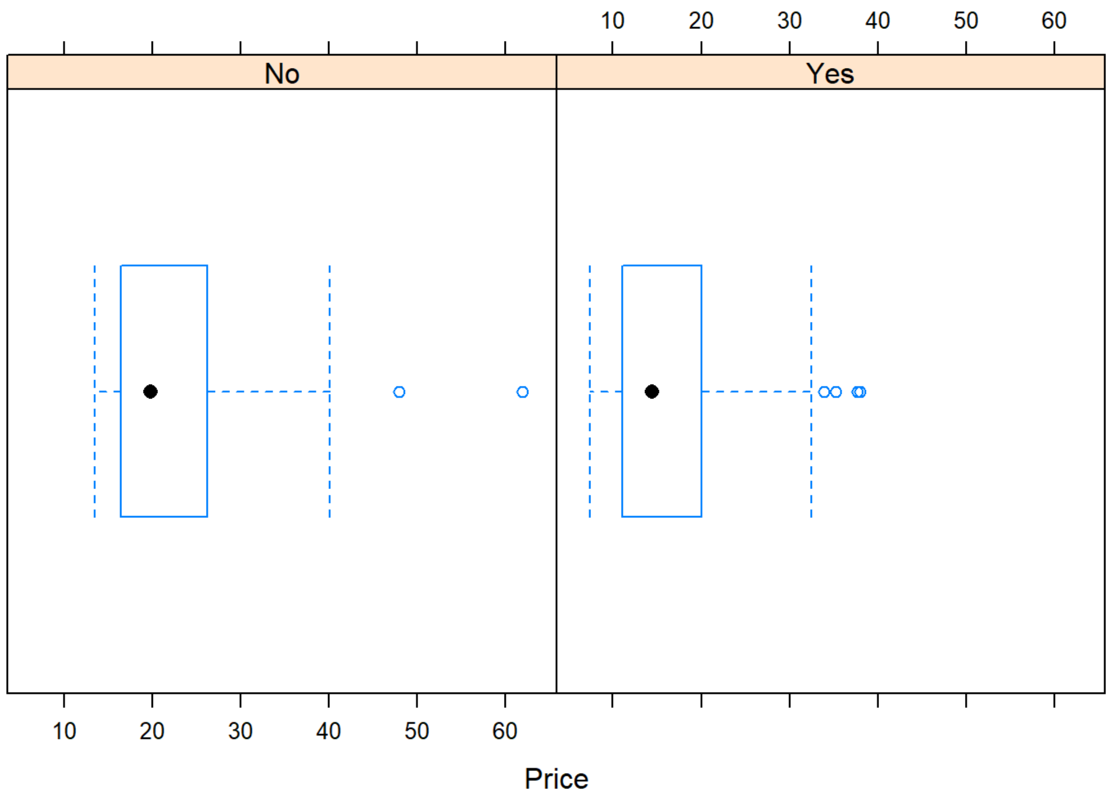
```
> bwplot( ~ Price | Type, data = Cars93)
```



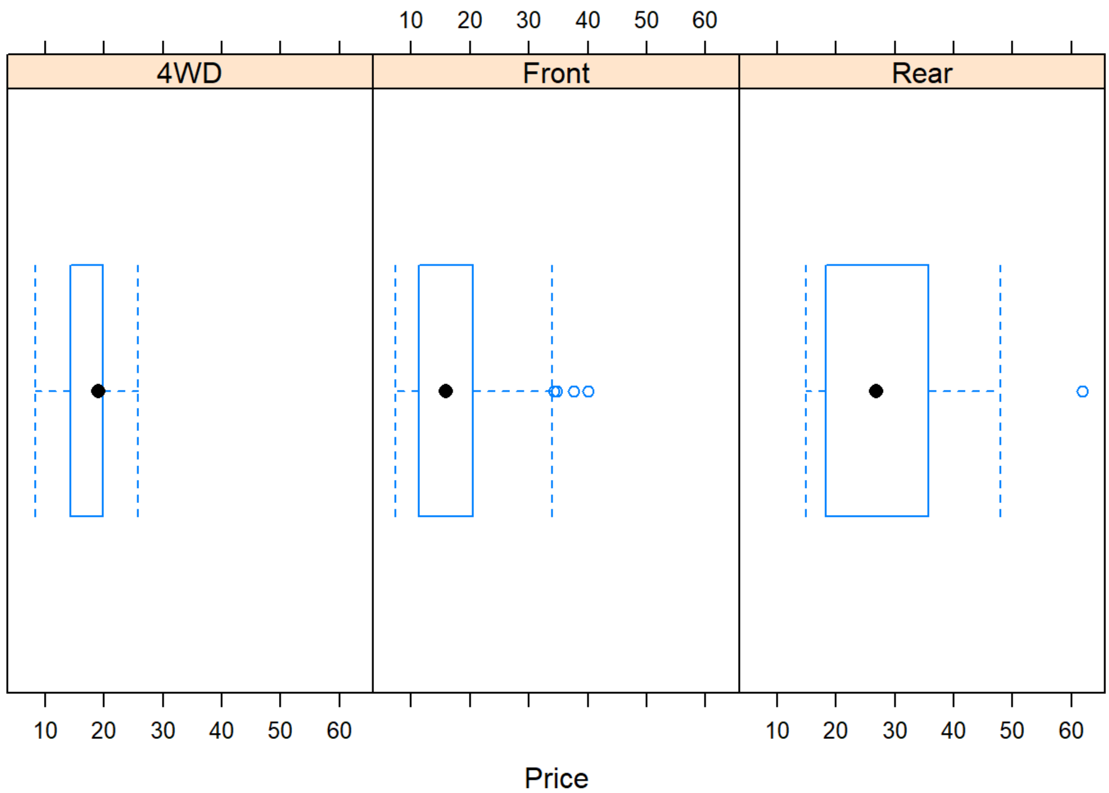

```
> bwplot( ~ Price | AirBags, data = Cars93)
```



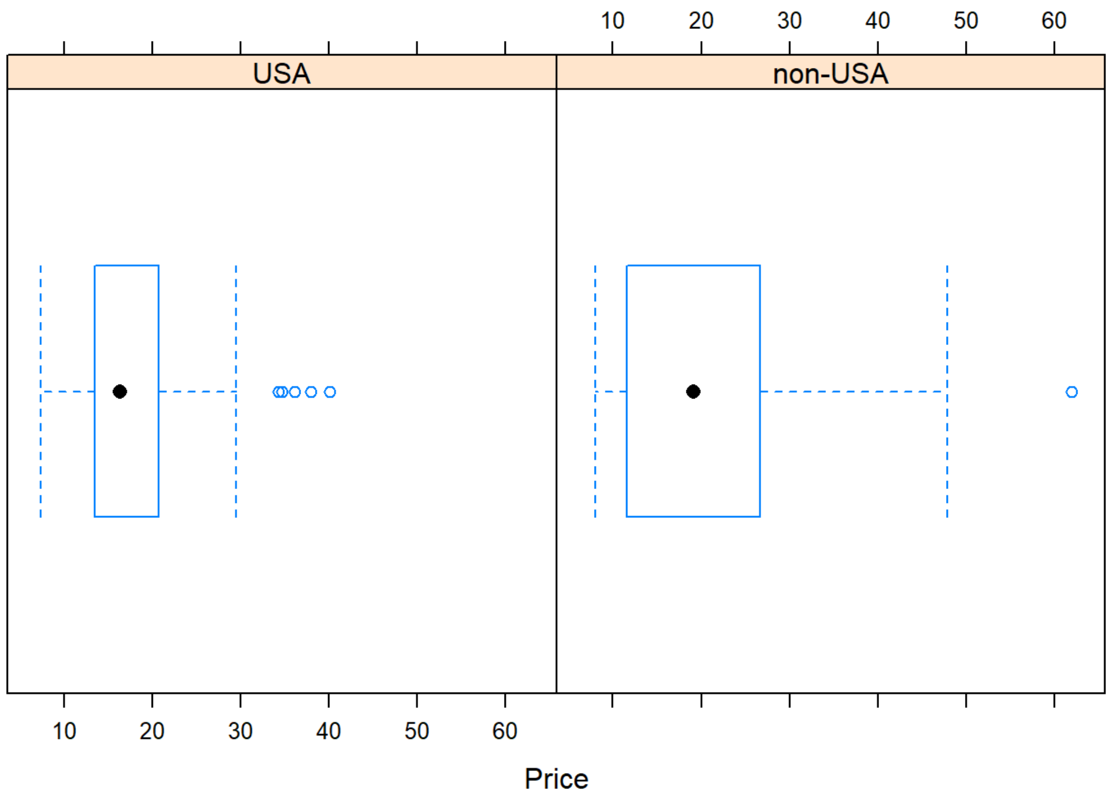
```
> bwplot( ~ Price | Man.trans.avail, data = Cars93)
```



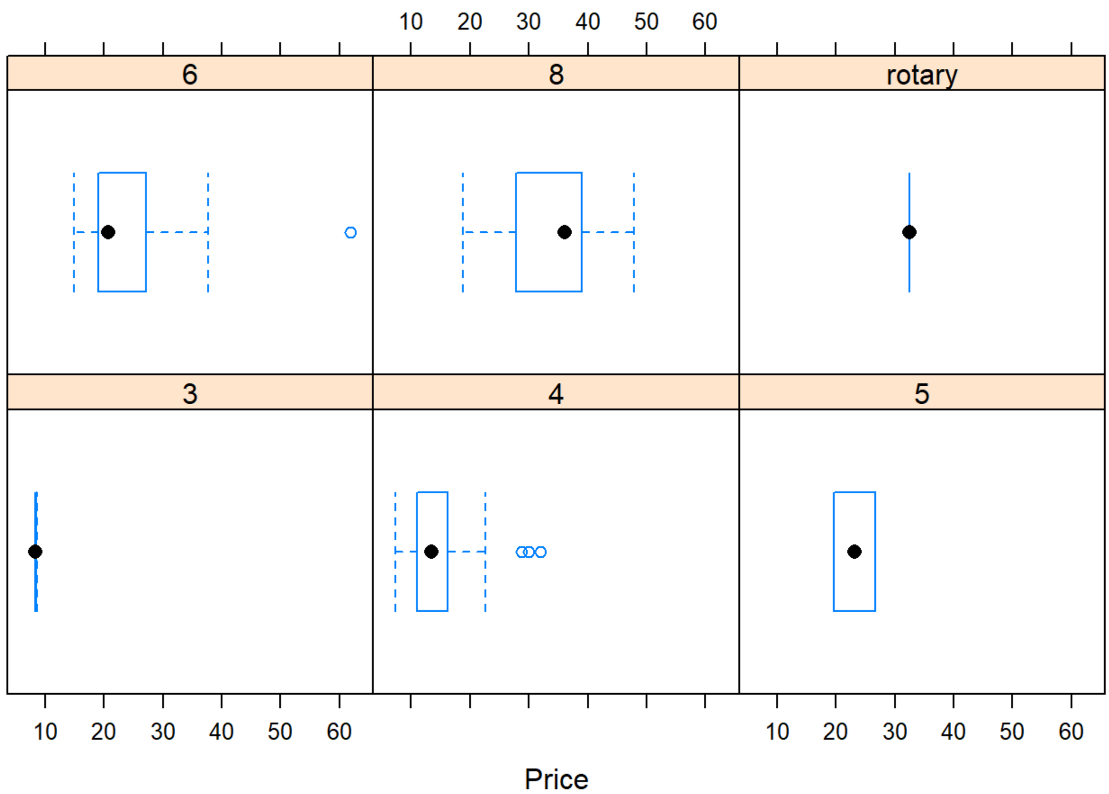

```
> bwplot( ~ Price | DriveTrain, data = Cars93)
```



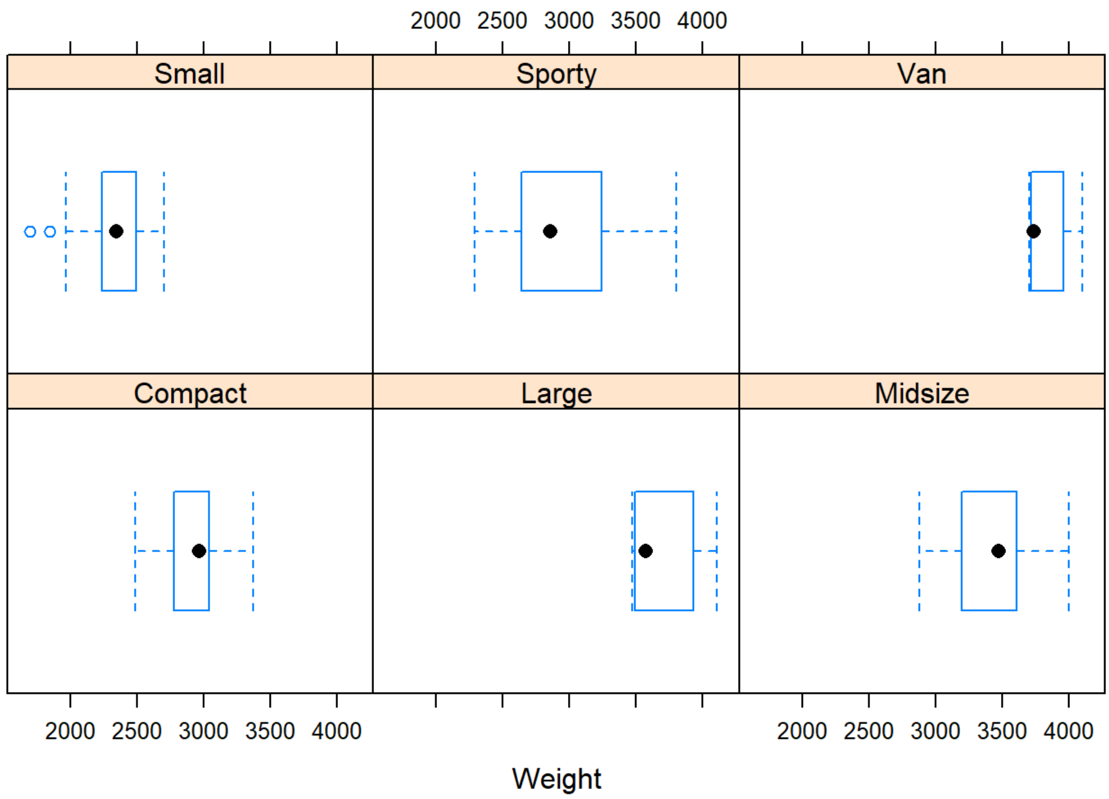
```
> bwplot( ~ Price | Origin, data = Cars93)
```



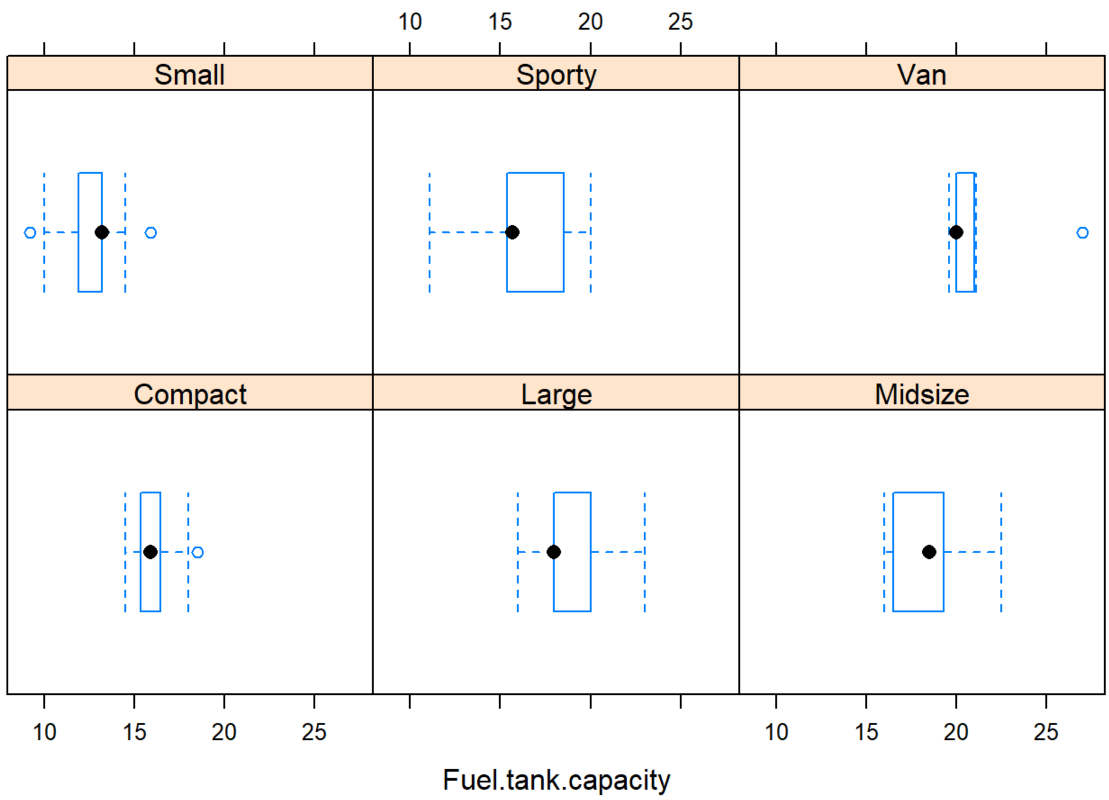

```
> bwplot( ~ Price | Cylinders , data = Cars93)
```



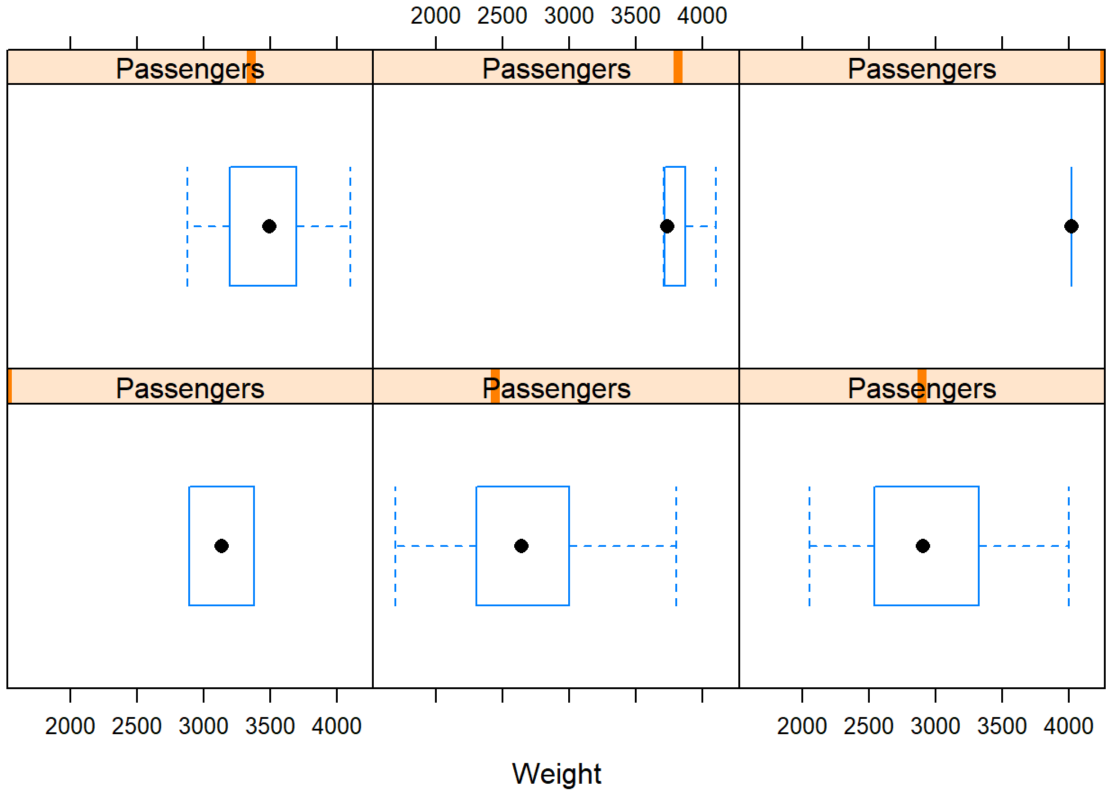
```
> bwplot( ~ Weight | Type , data = Cars93)
```



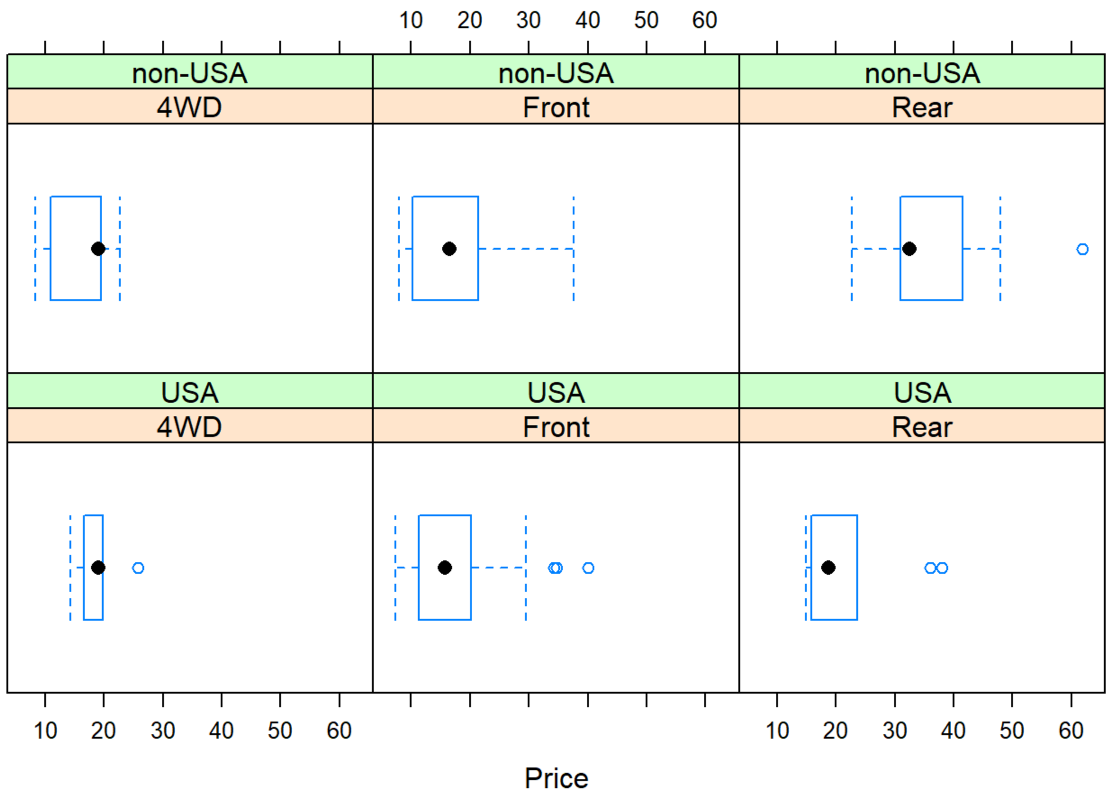

```
> bwplot( ~ Fuel.tank.capacity | Type , data = Cars93)
```



```
> bwplot( ~ Weight | Passengers , data = Cars93)
```




```
> bwplot( ~ Price | DriveTrain * Origin, data = Cars93)
```



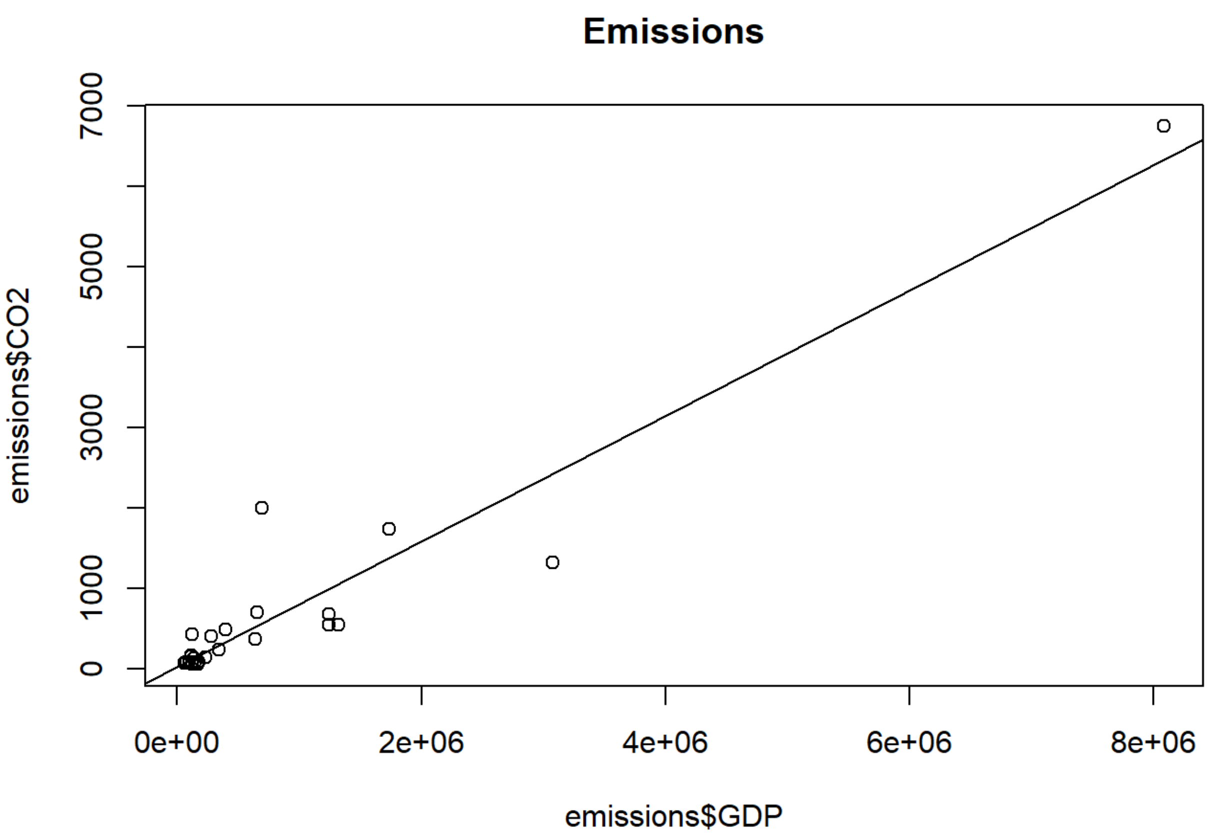
Numerical data

For the next example let's review the `emissions` data set containing gross domestic product (GDP), gross domestic product (GDP) per capita and CO2 emissions estimated for 26 countries in 1999.

```
> head(emissions)
                  GDP perCapita  CO2
UnitedStates  8083000     29647 6750
Japan         3080000     24409 1320
Germany       1740000     21197 1740
France        1320000     22381  550
UnitedKingdom 1242000     21010  675
Italy         1240000     21856  540
```

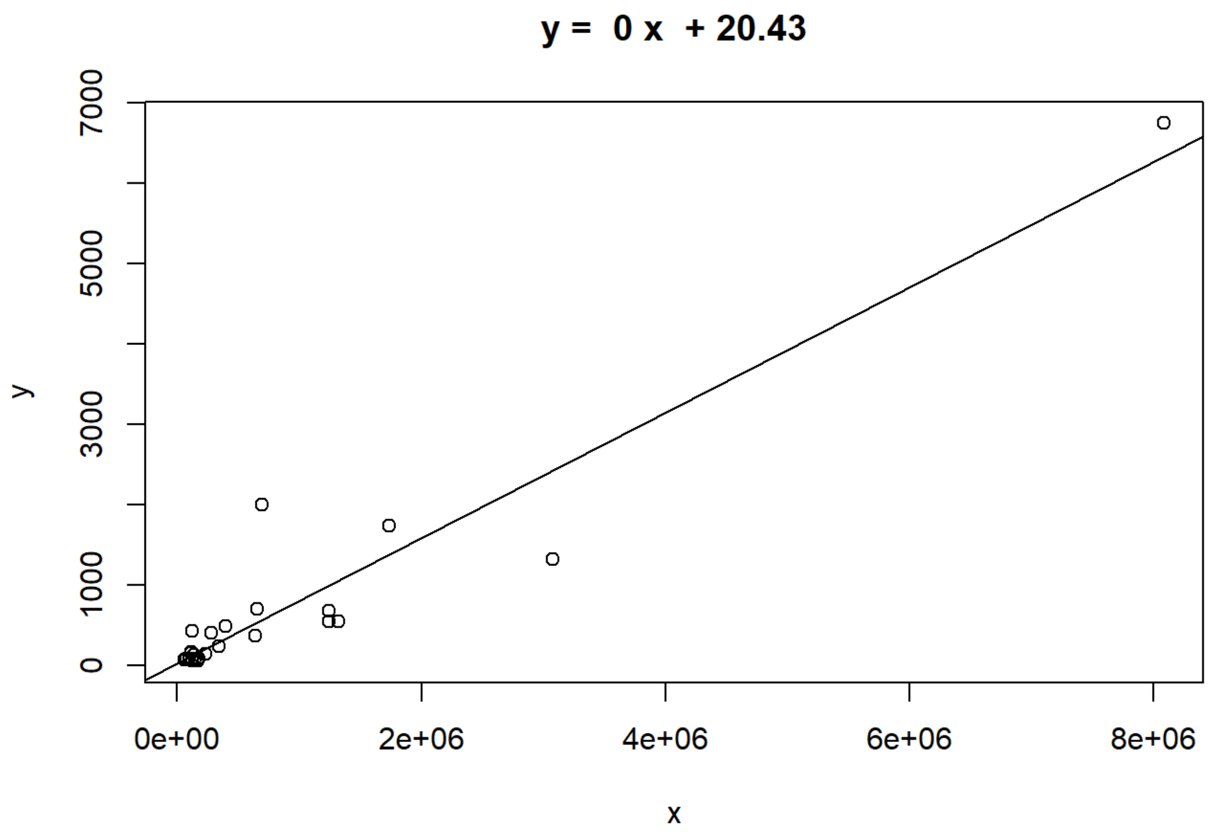
Is there a relationship between the gross domestic product and the CO2 emissions?

```
> cor(emissions$GDP, emissions$CO2)
[1] 0.95
> plot(emissions$CO2 ~ emissions$GDP, main = "Emissions")
> abline(lm(emissions$CO2 ~ emissions$GDP))
```



Another way was using `simple.lm` function from the `UsingR` package

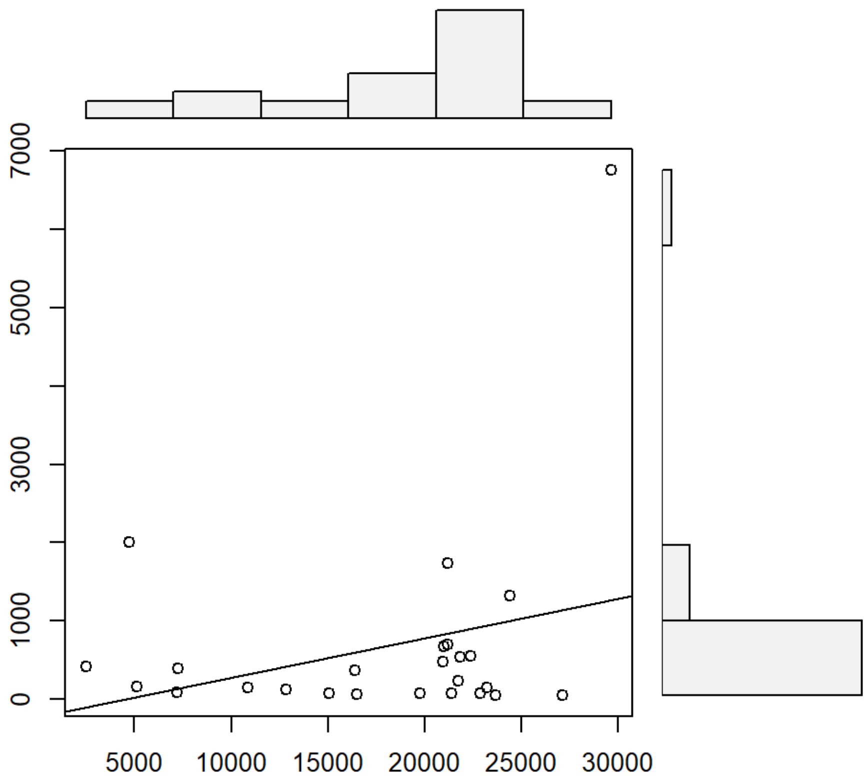
```
> simple.lm(emissions$GDP, emissions$CO2)
```




```
Call:
lm(formula = y ~ x)

Coefficients:
(Intercept)            x
   2.04e+01     7.81e-04
```

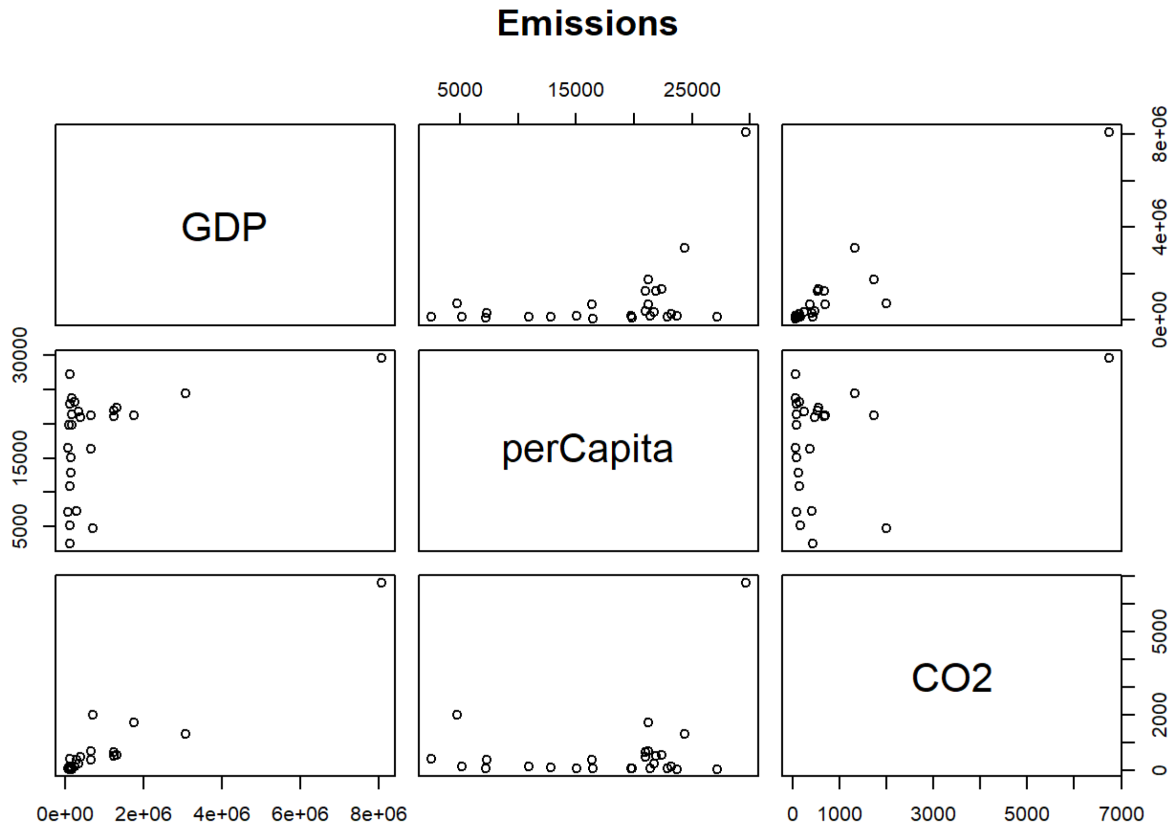
We can also see the distributions and the relation ship at the same time, we can use `simple.scatterplot` function.

```
> simple.scatterplot(emissions$perCapita, emissions$CO2)
```



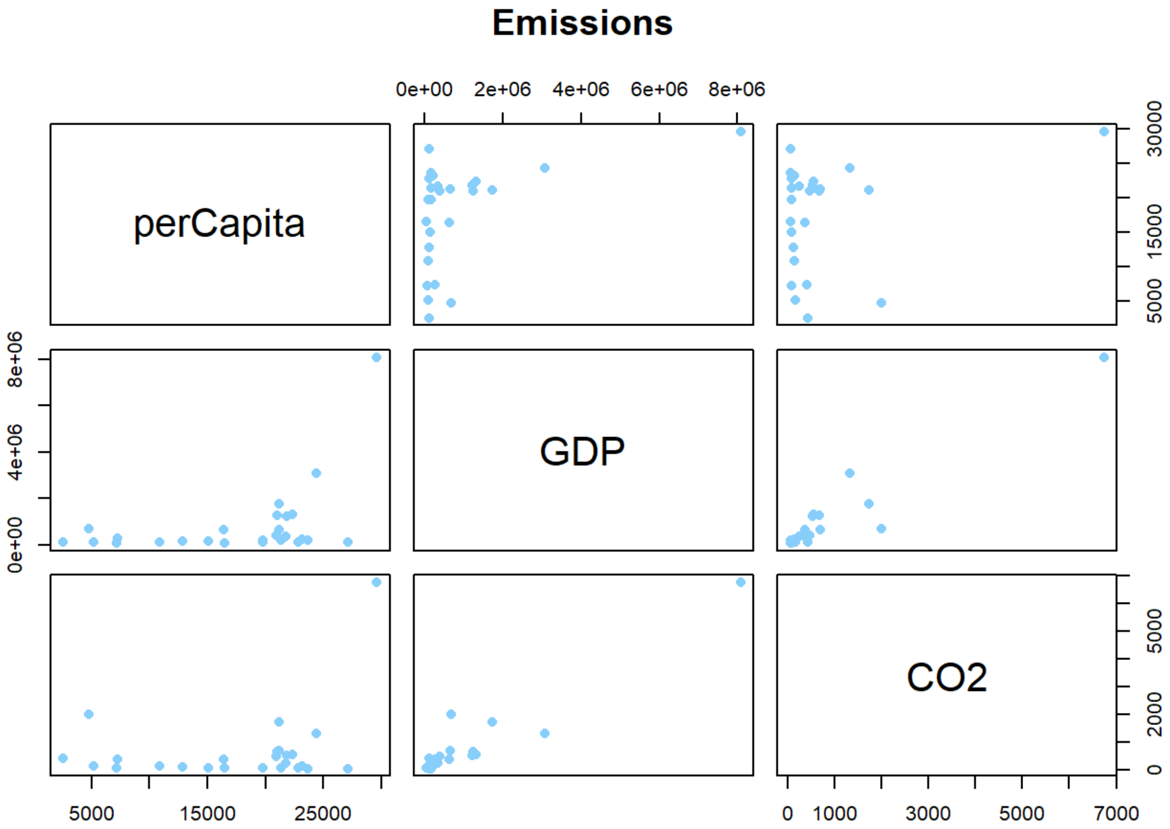
And we see that we can make plots for all the variables in the data frame simultaneously using the `pairs` function, there are a lot customize attributes for this function

```
> pairs(emissions, main = "Emissions")
```



For example using this syntax we can chose which variables to include in the model and how to order them. Also as we already saw by using `col` and `pch` we can change the color and the symbol of data representation.

```
> pairs( ~ perCapita + GDP + CO2, data = emissions,
+        main = "Emissions",
+        col = "lightskyblue",
+        pch = 16)
```

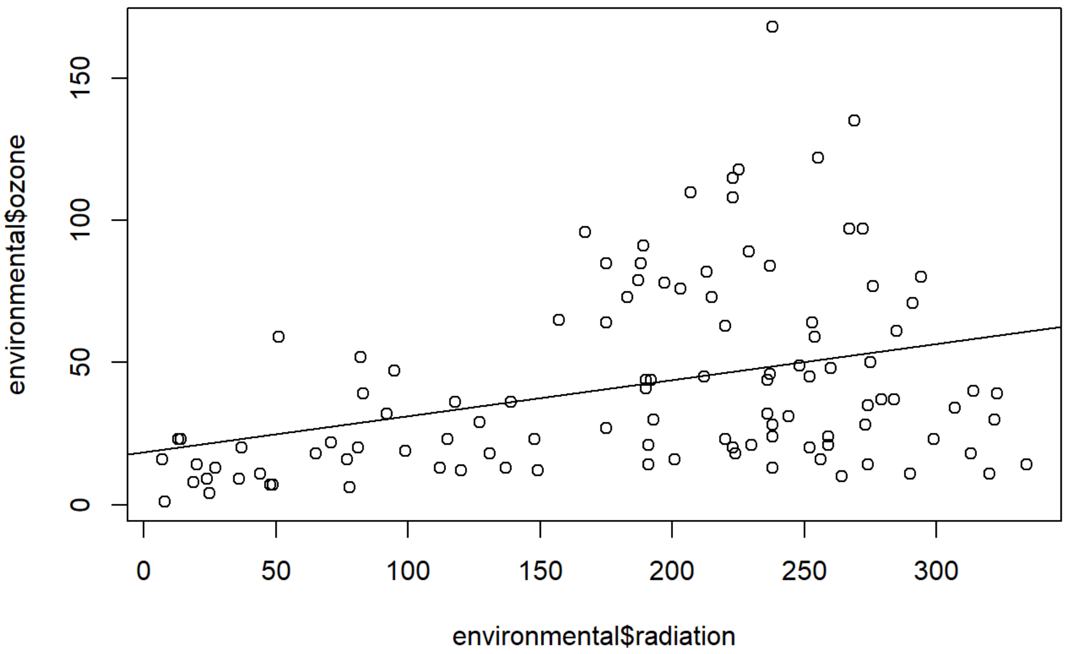


For the next example we are going to review `environmental` data frame from `lattice` package showing daily measurements of average ozone concentration (of hourly measurements) in parts per billion, solar radiation (from 08:00 to 12:00) in langleys, maximum temperature in Fahrenheit and average wind speed (at 07:00 and 10:00) in miles per hour in New York City from May to September of 1973.

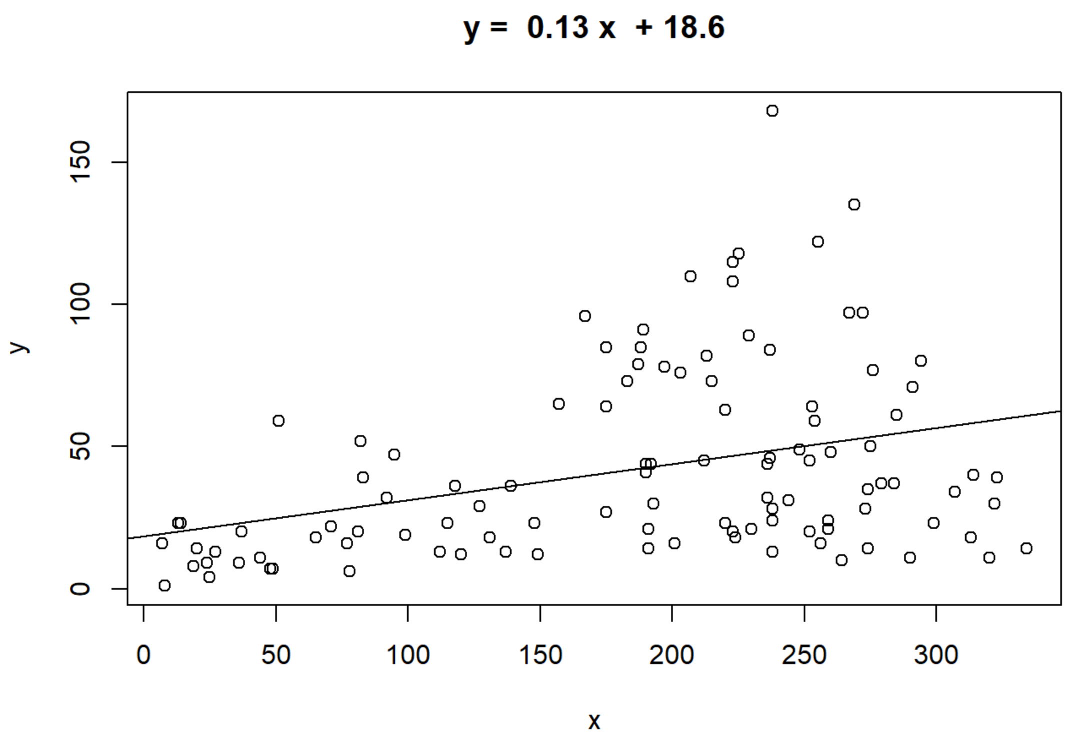
```
> head(environmental)
  ozone radiation temperature wind
1    41       190          67  7.4
2    36       118          72  8.0
3    12       149          74 12.6
4    18       313          62 11.5
5    23       299          65  8.6
6    19        99          59 13.8
```

By using the base plotting system we can plot the data for ozone and radiation as above

```
> cor(environmental$radiation, environmental$ozone)
[1] 0.35
> plot(environmental$ozone ~ environmental$radiation)
> abline(lm(environmental$ozone ~
environmental$radiation))
```

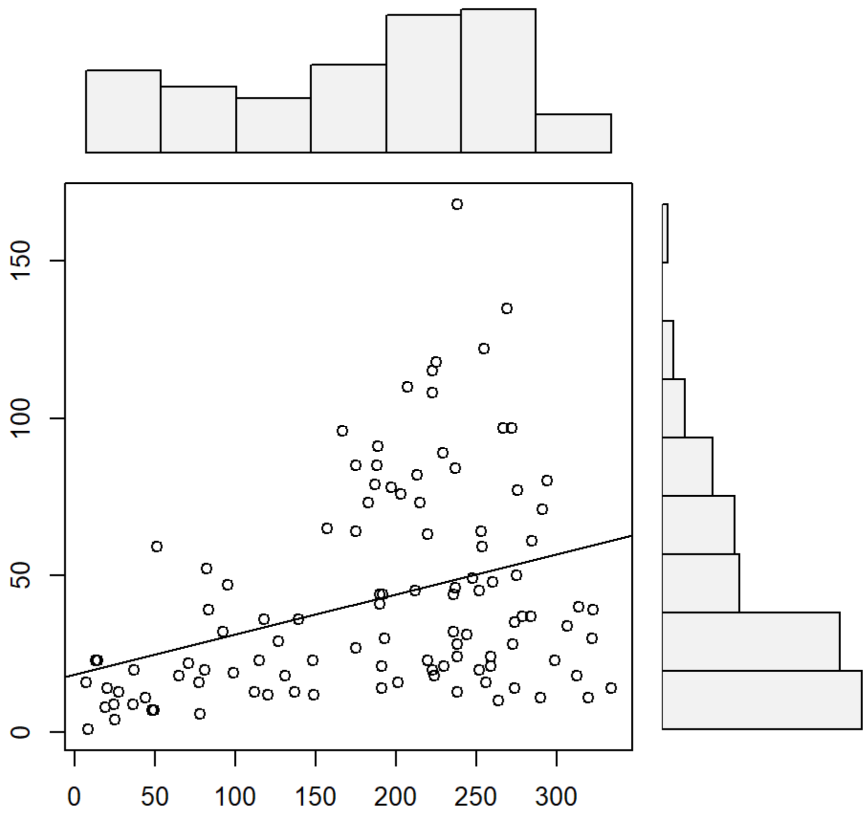



```
> simple.lm(environmental$radiation, environmental$ozone)
```

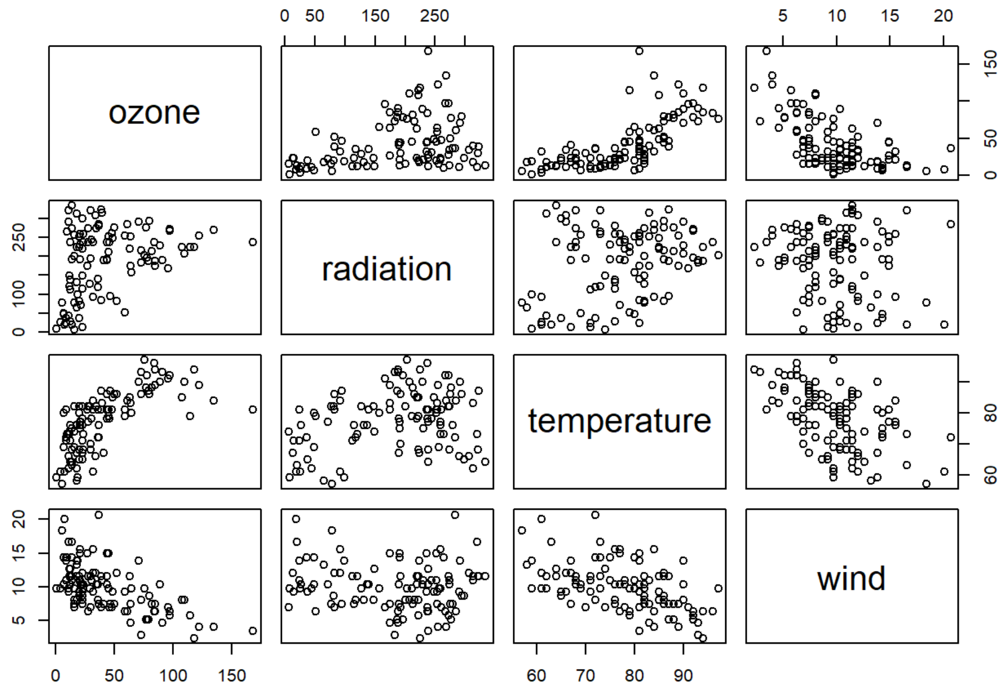


```
Call:
lm(formula = y ~ x)

Coefficients:
(Intercept)            x
     18.599        0.127
```

```
> simple.scatterplot(environmental$radiation, 
environmental$ozone)
```

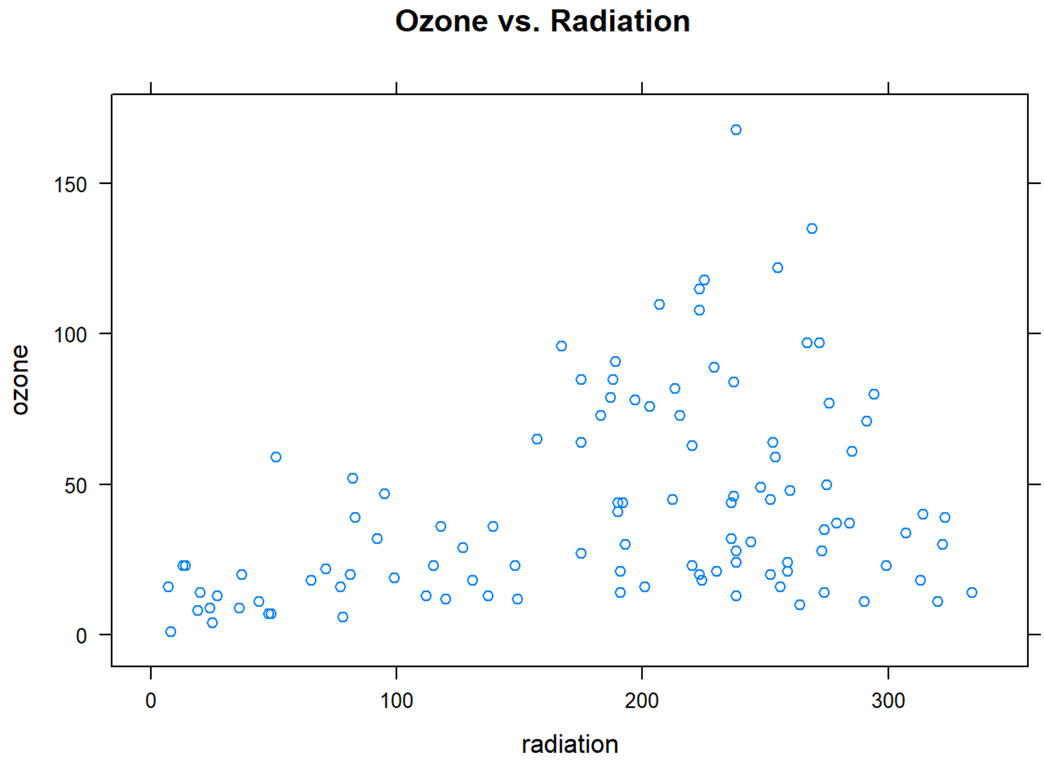


```
> pairs(environmental)
```



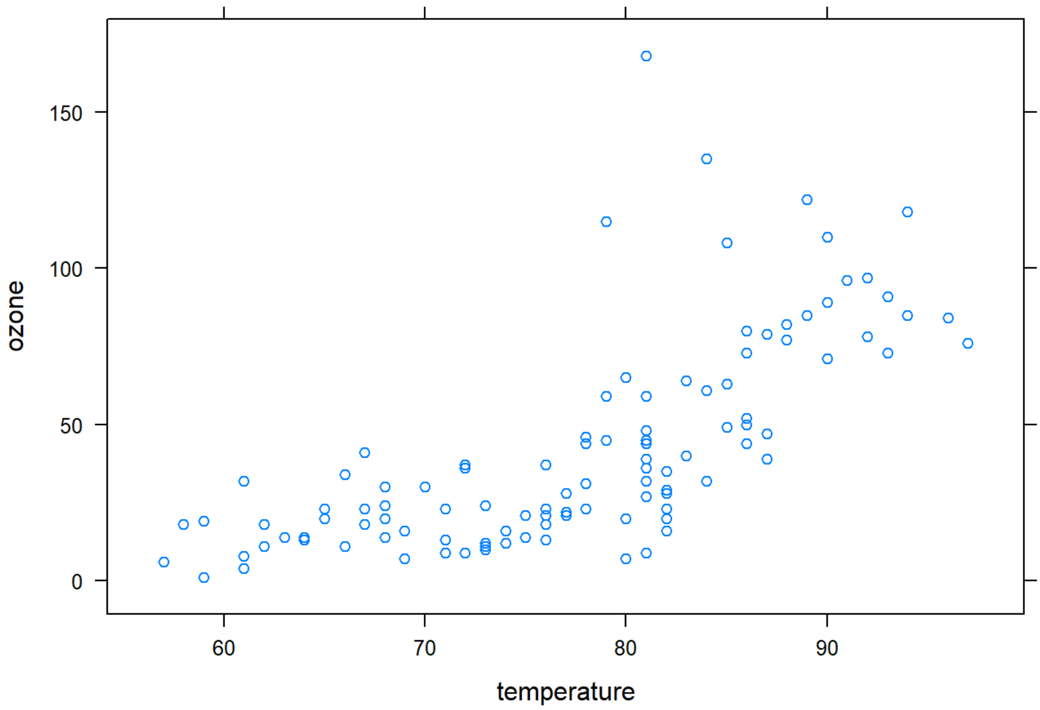
We can use `xyplot` from `lattice` package to make the scatterplot of ozone and radiation. We use the same syntax as above `response ~ predictor`

```
> xyplot(ozone ~ radiation, data = environmental,
+        main = "Ozone vs. Radiation")
```



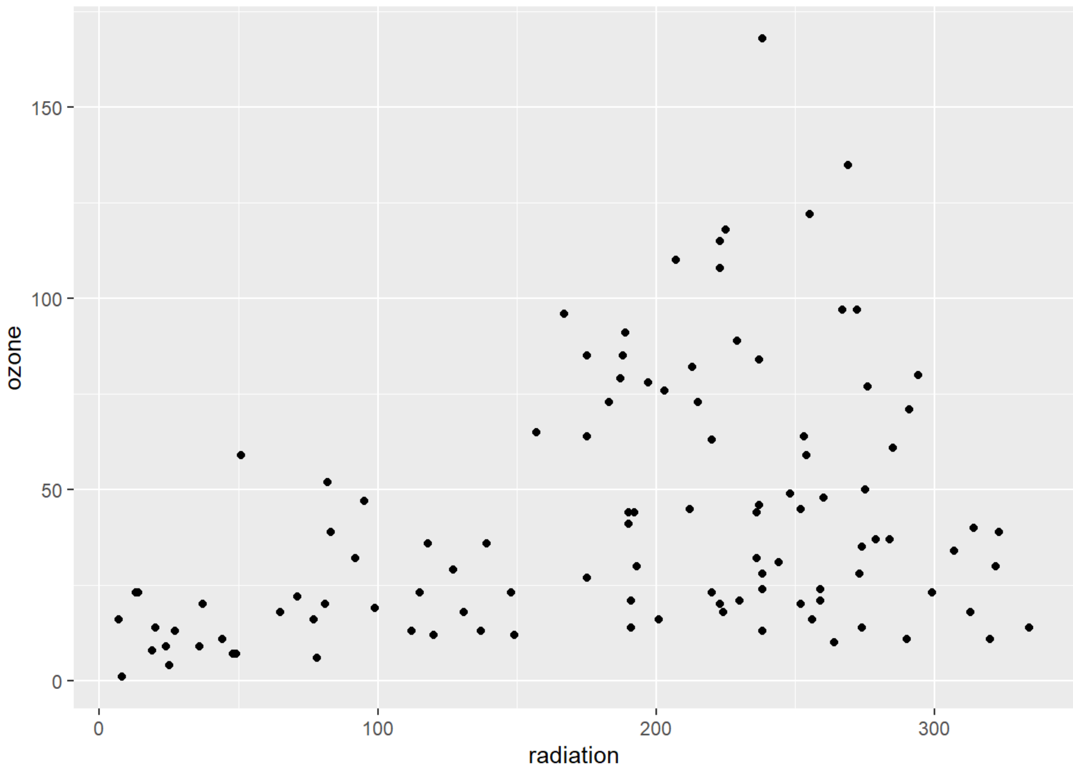
Also we can see the relation between ozone and temperature

```
> xyplot(ozone ~ temperature, data = environmental)
```

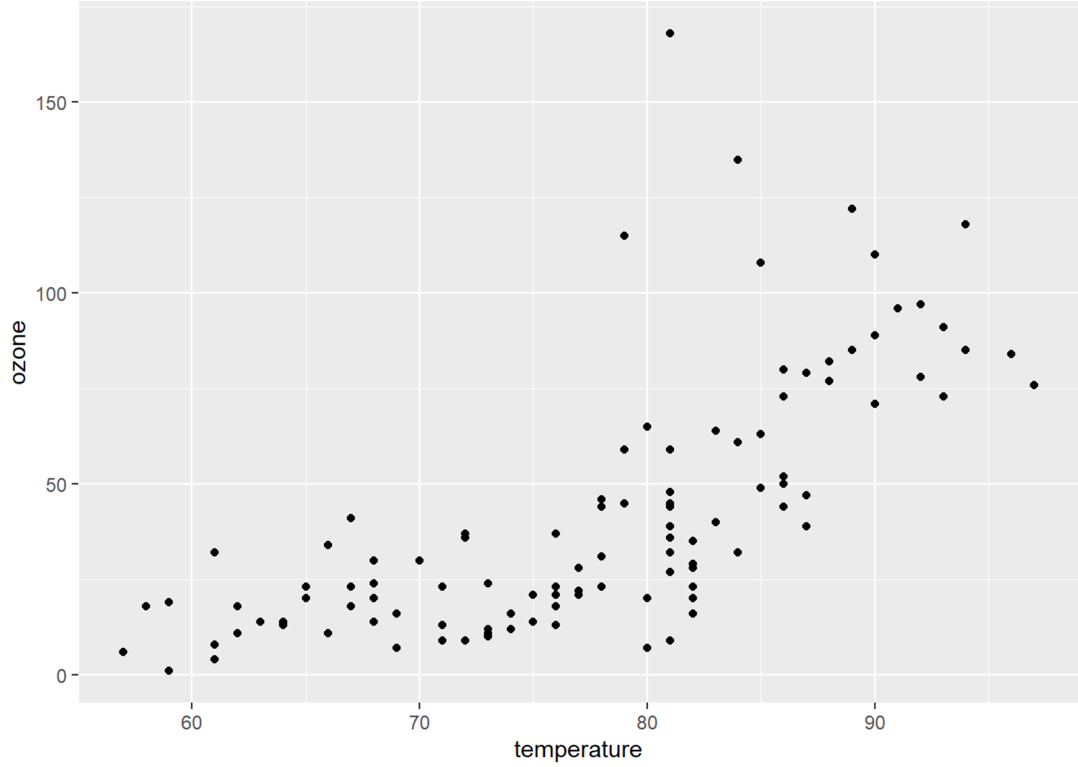


We can also use `qplot` from `ggplot` package to make the scatterplot of ozone and radiation.

```
> qplot(radiation, ozone, data = environmental)
```



```
> qplot(temperature, ozone, data = environmental)
```

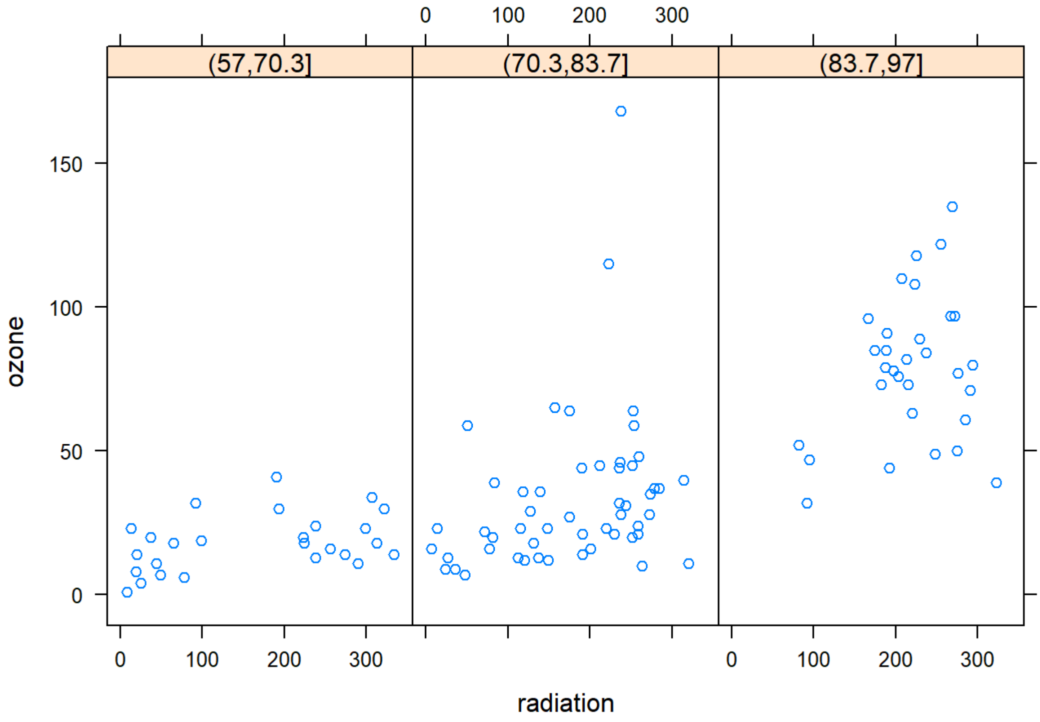


Does the relationship between ozone and radiation change as the temperature changes? We can cut the temperature interval in 3 subsets

```
> summary(environmental$temperature)
   Min. 1st Qu.  Median    Mean 3rd Qu.    Max. 
     57      71      79      78      84      97 
> temperature.cut <- cut(environmental$temperature, 3)
```

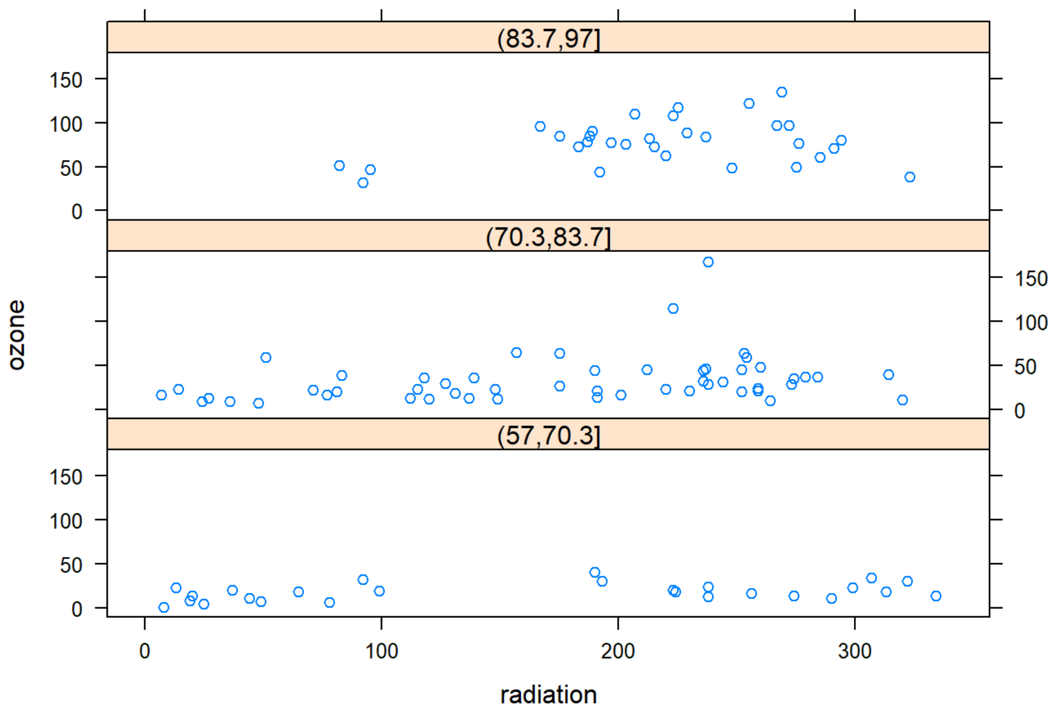
Continuing with `lattice` package we can make a scatterplot for every subset of temperature intervals

```
> xyplot(ozone ~ radiation | temperature.cut, data =
environmental)
```



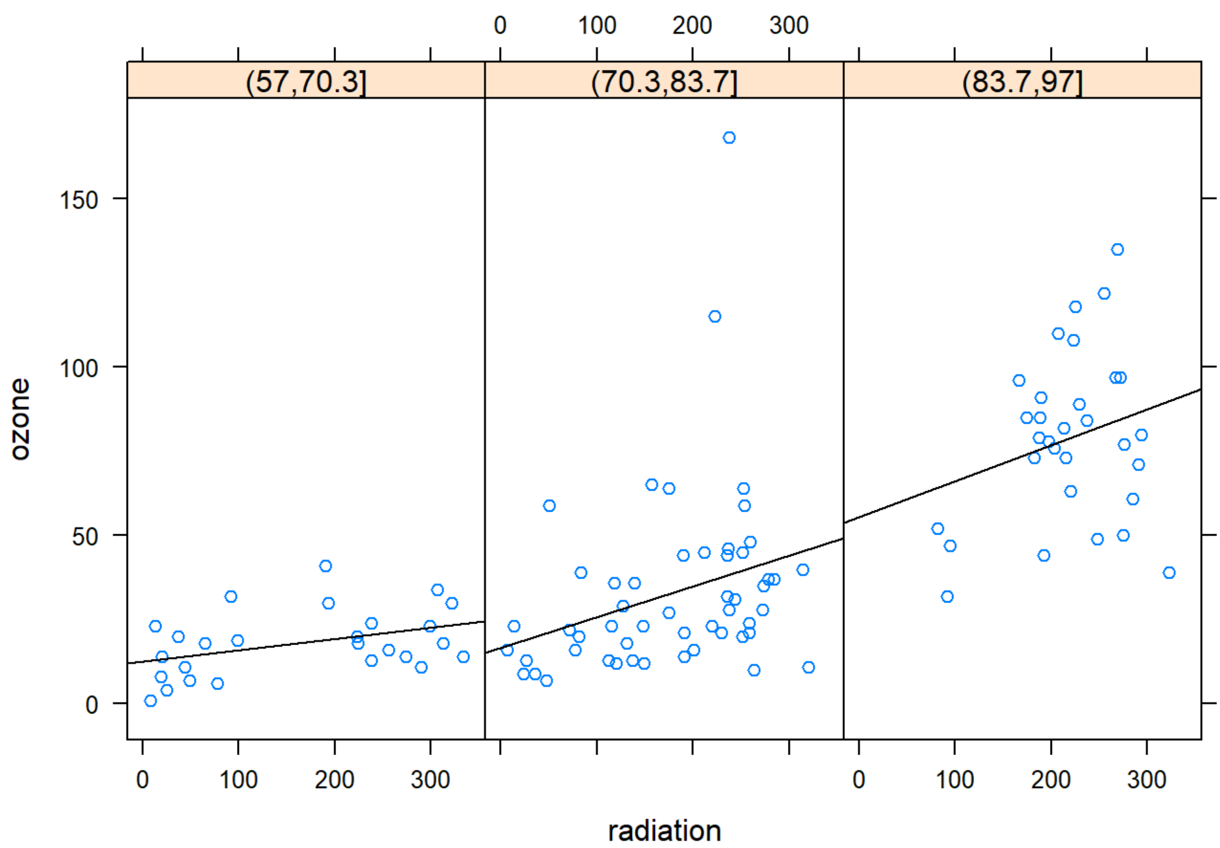
We can tune it up if we want. We can order the graphics in one column for example.

```
> xyplot(ozone ~ radiation | temperature.cut, data =
environmental, layout = c(1, 3))
```



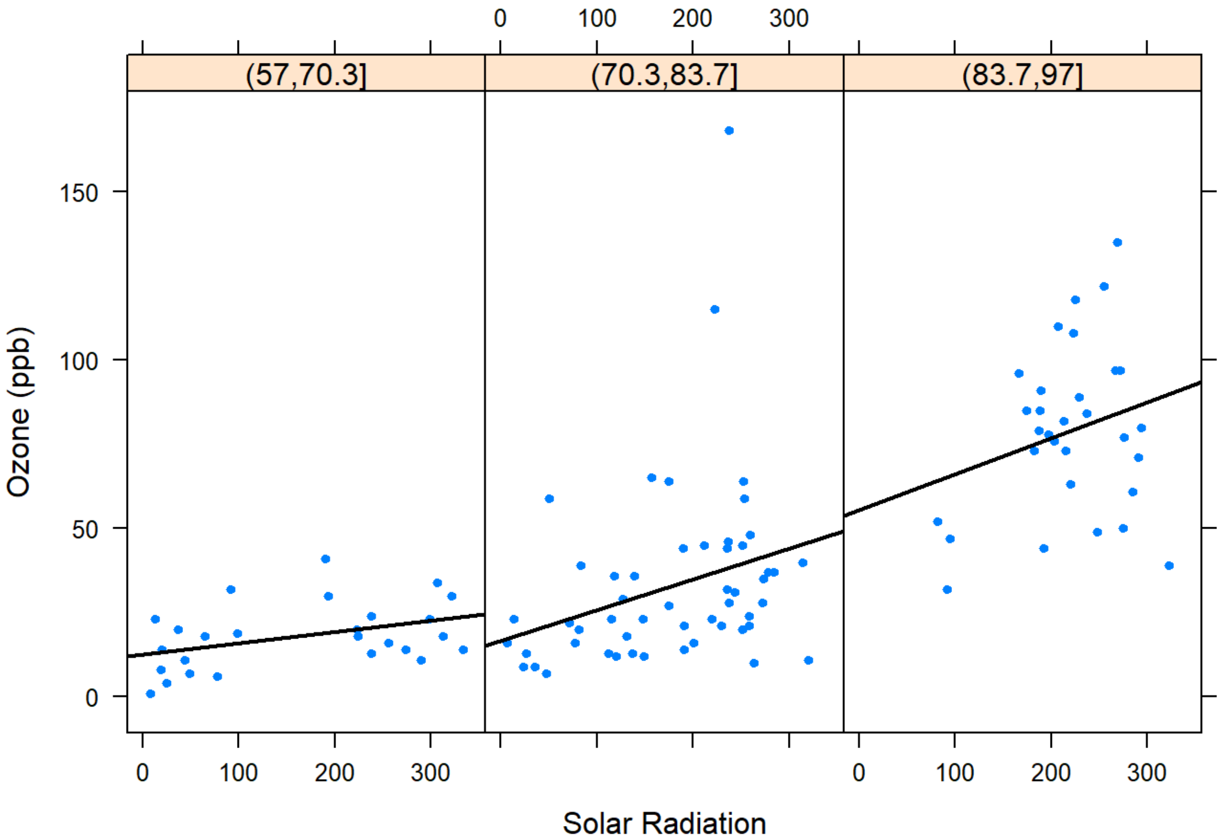
We can also add additional function to the panels. In this example we calculate a linear model and add a linear regression line to the panels.

```
> xyplot(ozone ~ radiation | temperature.cut, data =
environmental,
+         panel = function(x, y, ...){
+           panel.xyplot(x, y, ...)
+           fit <- lm(y ~ x)
+           panel.abline(fit)
+         })
```



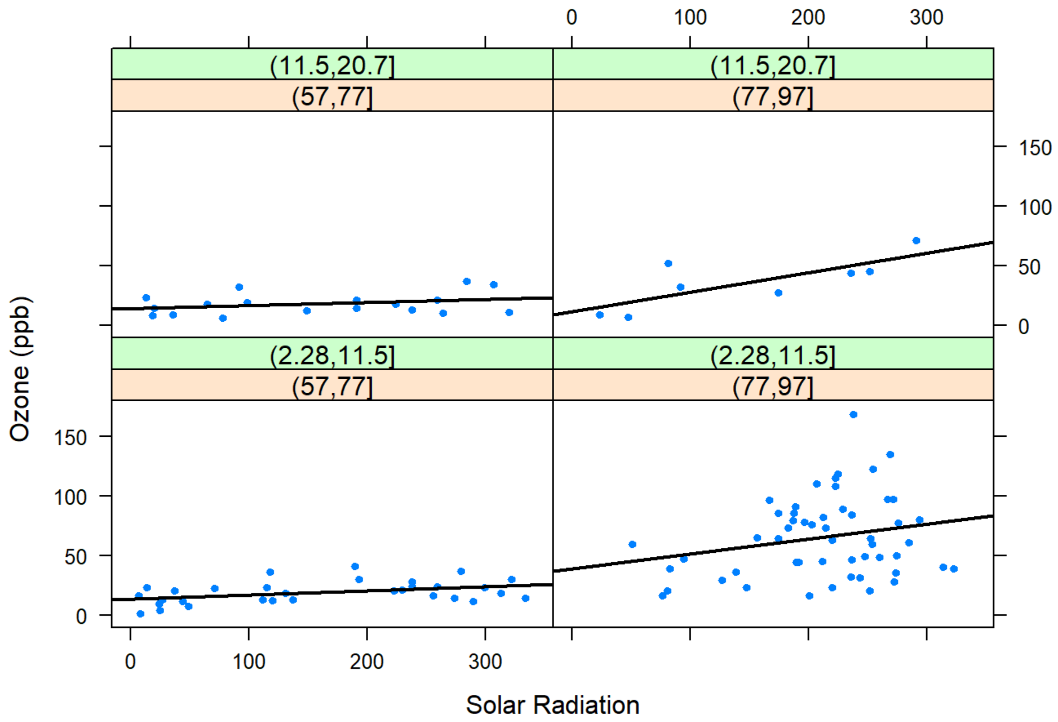
We can also change graphic's labels, colors and symbols.

```
> xyplot(ozone ~ radiation | temperature.cut, data =
environmental,
+         panel = function(x, y, ...){
+           panel.xyplot(x, y, ...)
+           fit <- lm(y ~ x)
+           panel.abline(fit, lwd = 2)
+         },
+         xlab = "Solar Radiation",
+         ylab = "Ozone (ppb)",
+         pch = 20)
```



Let's see how ozone and solar radiation change when both temperature and wind change?

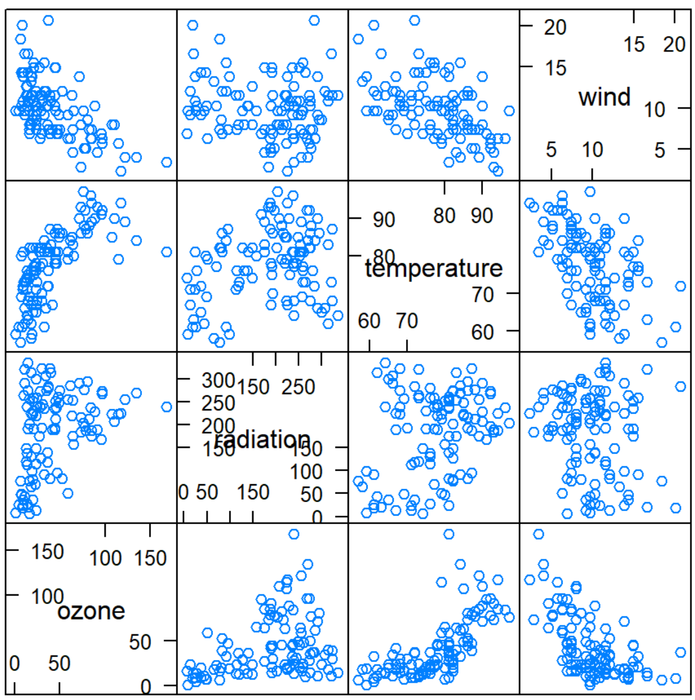
```
> temperature.cut <- cut(environmental$temperature, 2)
> wind.cut <- cut(environmental$wind, 2)
> xyplot(ozone ~ radiation | temperature.cut * wind.cut,
data = environmental,
+         panel = function(x, y, ...){
+           panel.xyplot(x, y, ...)
+           fit <- lm(y ~ x)
+           panel.abline(fit, lwd = 2)
+         },
+         xlab = "Solar Radiation",
+         ylab = "Ozone (ppb)",
+         pch = 20)
```



As you see `xyplot` function is useful of making this kind of conditioning plots where we plot the relationship between two variables by conditioning on the values of third variable.

`splom` form `lattice` is similar to `pairs` function base graphics package

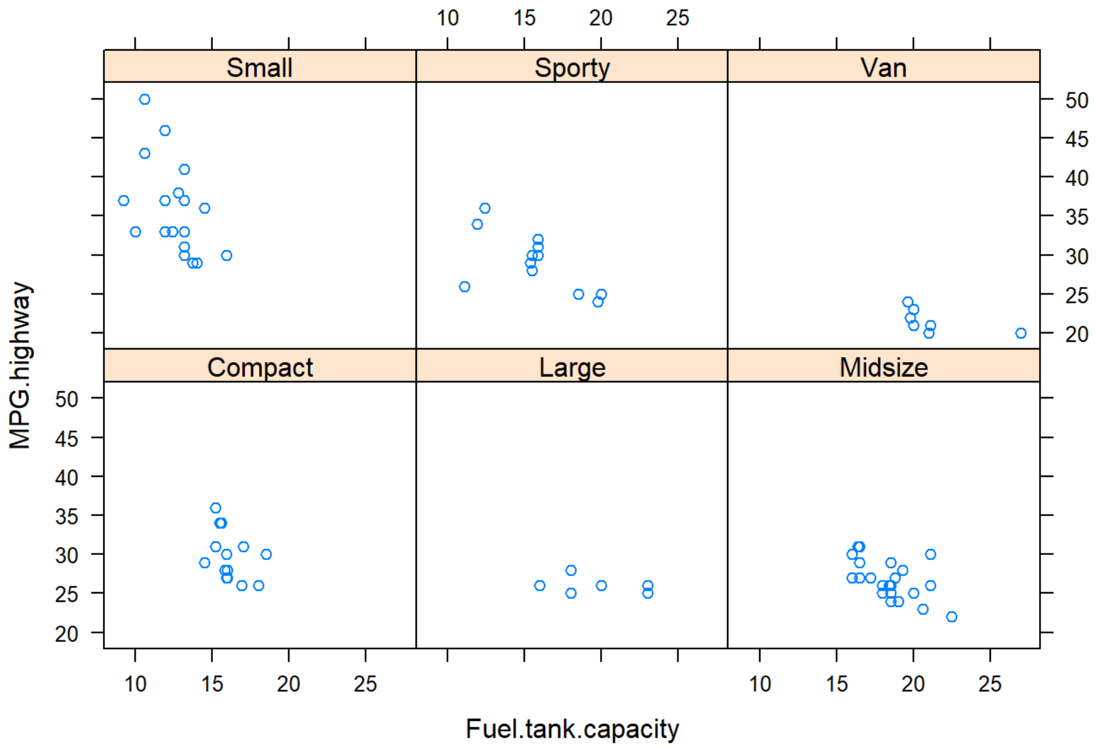
```
> splom( ~ environmental)
```



Scatter Plot Matrix

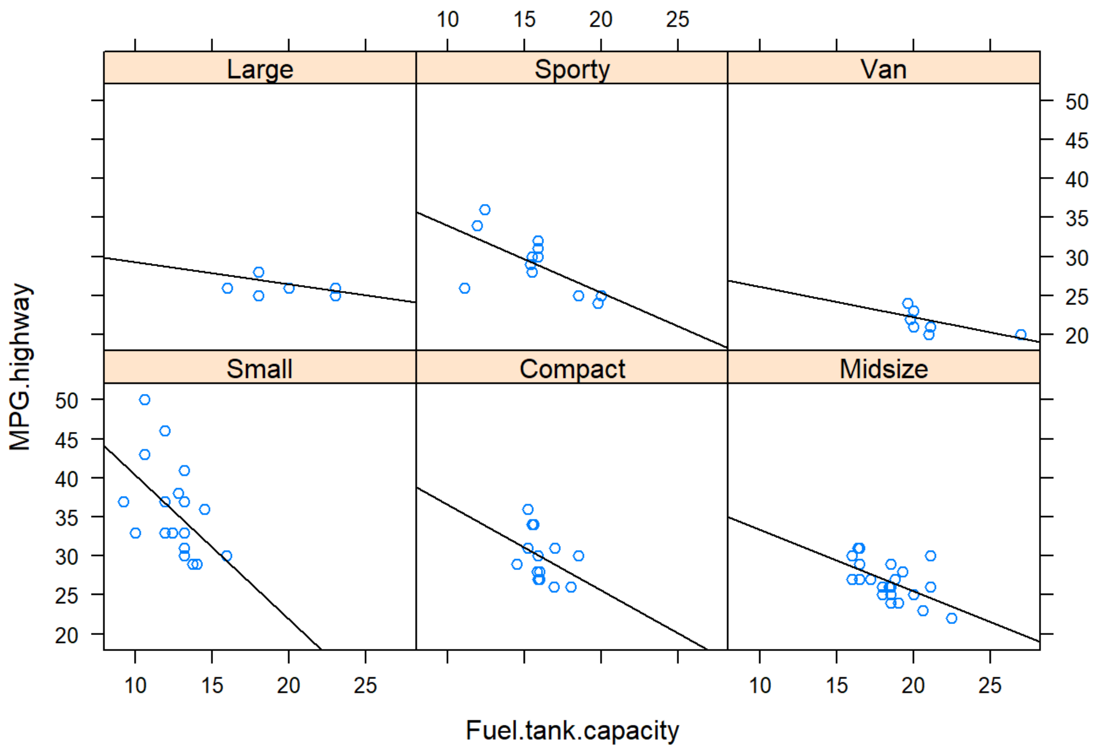
Another example again with `Cars93` data frame
for `MPG.highway` and `Fuel.tank.capacity`

```
> xyplot(MPG.highway ~ Fuel.tank.capacity | Type, data =
Cars93)
```



Let's also add the linear regression lines

```
> plot.regression = function(x,y) {
+   panel.xyplot(x,y)
+   panel.abline(lm(y~x))
+ }
> xyplot(MPG.highway ~ Fuel.tank.capacity | Type, panel =
plot.regression)
```

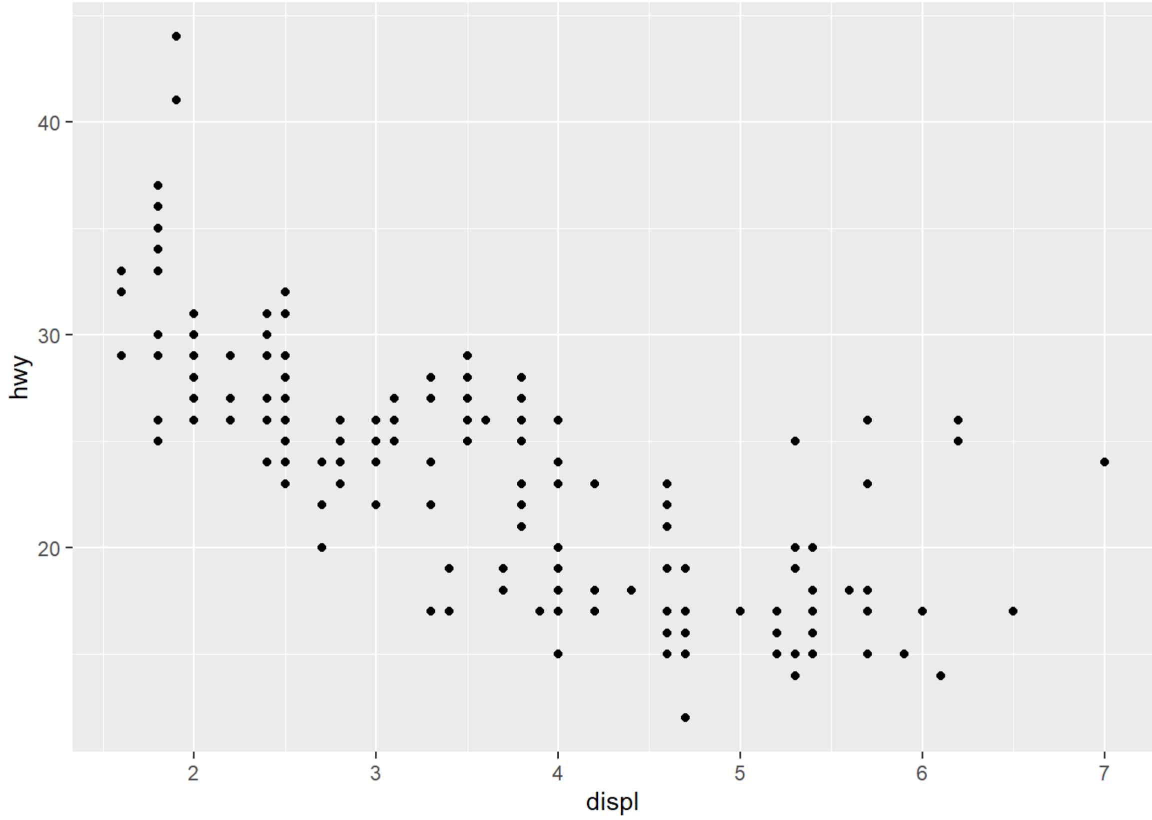


ggplot2 examples

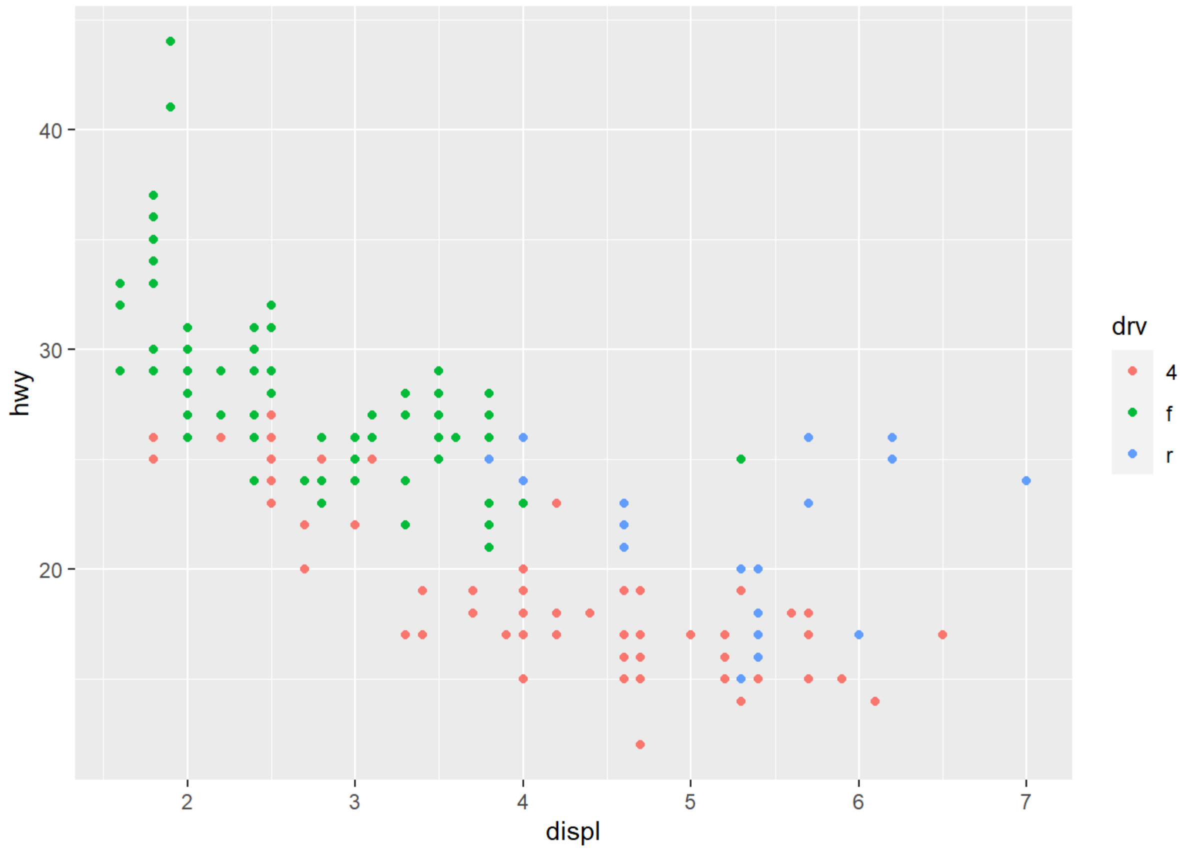
Another example with the `mpg` data frame reviewed using `qplot` function from `ggplot` package

```
> head(mpg)
# A tibble: 6 x 11
  manufacturer model displ  year   cyl trans      drv
cty   hwy fl     class
  <chr>        <chr> <dbl> <int> <int> <chr>      <chr>
<int> <int> <chr> <chr>
1 audi         a4      1.8  1999     4 auto(l5)   f
18      29 p     compa~
2 audi         a4      1.8  1999     4 manual(m5) f
21      29 p     compa~
3 audi         a4      2    2008     4 manual(m6) f
20      31 p     compa~
4 audi         a4      2    2008     4 auto(av)   f
21      30 p     compa~
5 audi         a4      2.8  1999     6 auto(l5)   f
16      26 p     compa~
```

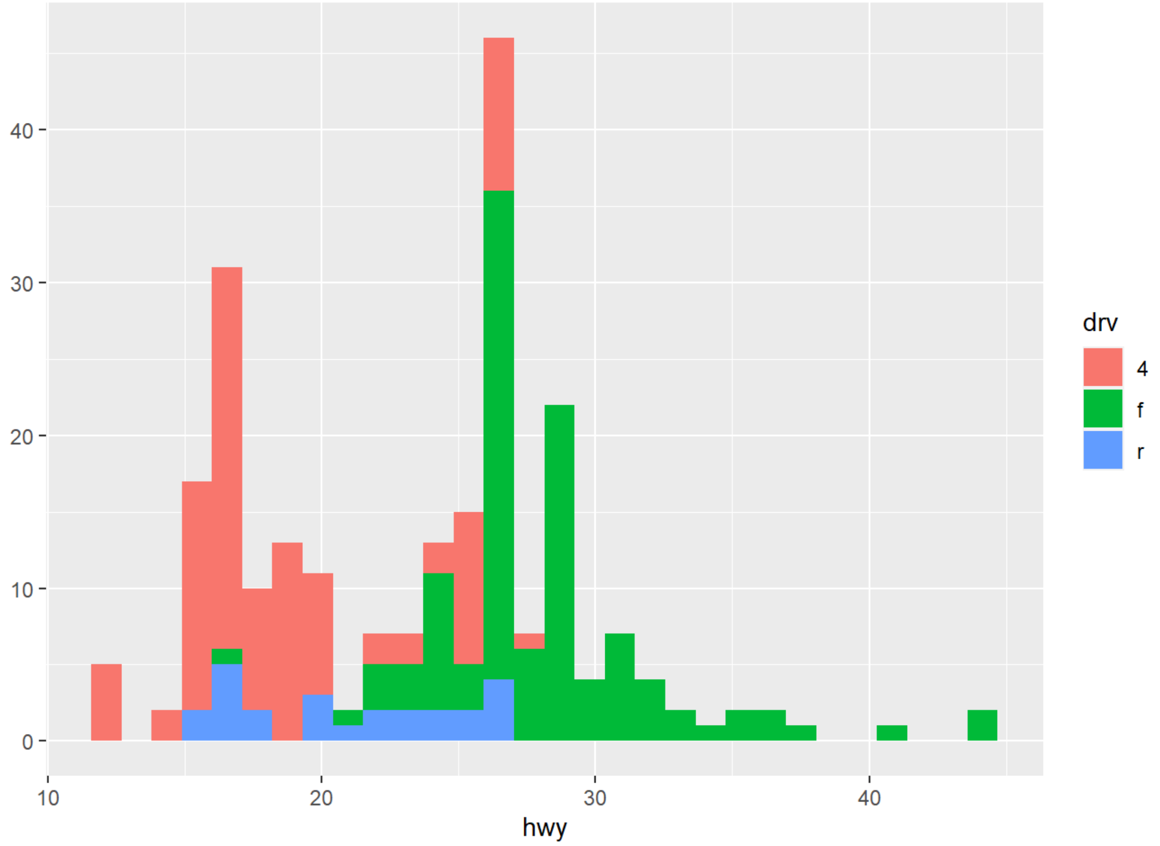
```
6 audi          a4       2.8   1999      6 manual(m5) f
18     26 p     compa~
> qplot(displ, hwy, data = mpg)
```




```
> qplot(displ, hwy, data = mpg, color = drv)
```

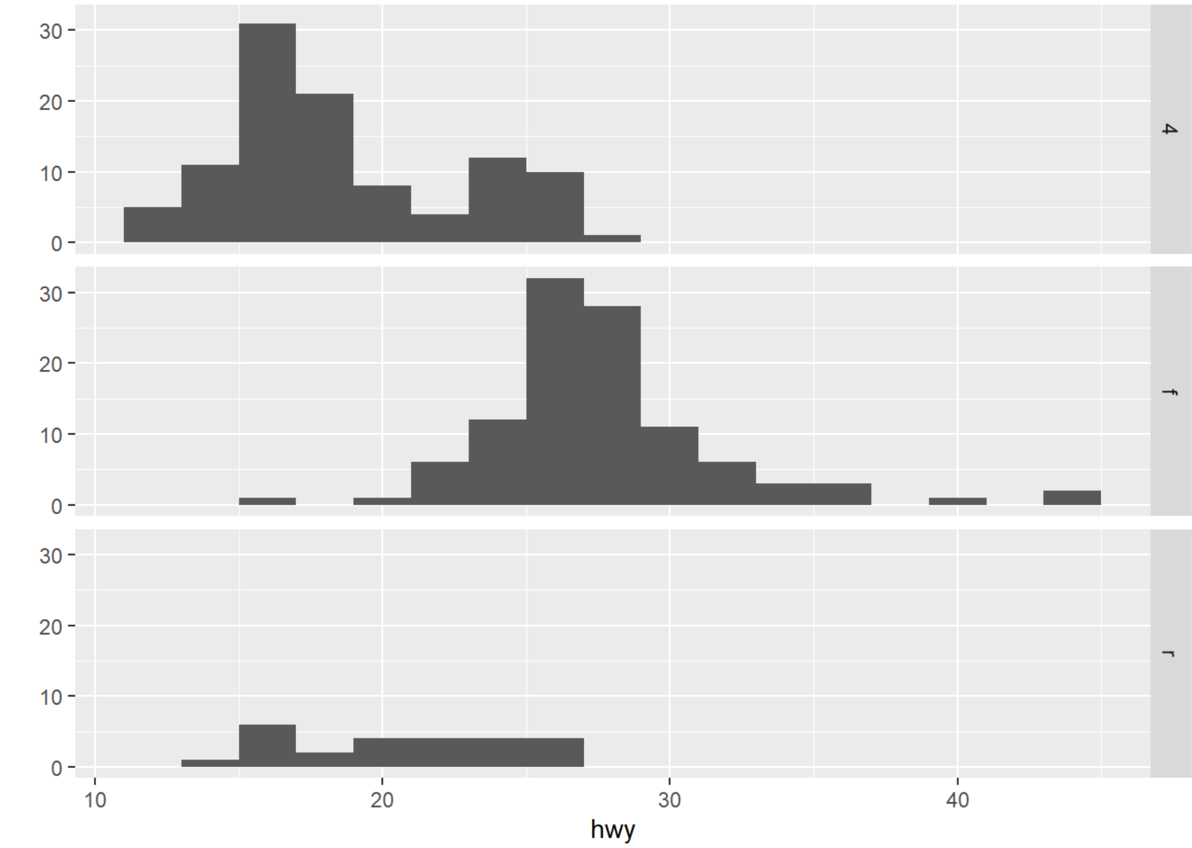


```
> qplot(hwy, data = mpg, fill = drv)
`stat_bin()` using `bins = 30`. Pick better value with
`binwidth`.
```

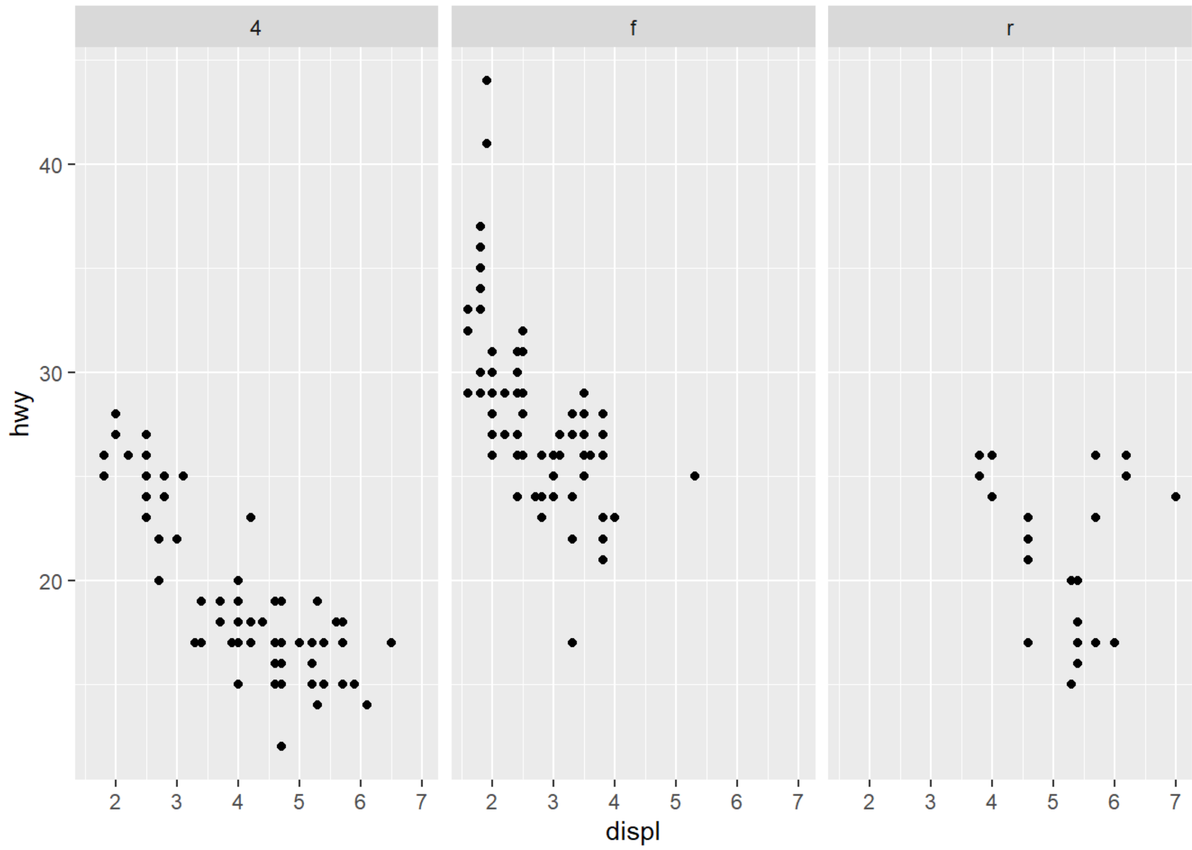


`facets` are like panels in `lattice`. The idea is that you can create a separate plot for any subset of your data which are determined by a factor variable. All of this plots are depicted in different panels in one and the same figure. When the factor variable is on the left side of the `~` its categories determine the facets in the different rows. When it is on the right side it determines the facets in the different columns. `.` indicates that we don't have an argument, it can also be empty.

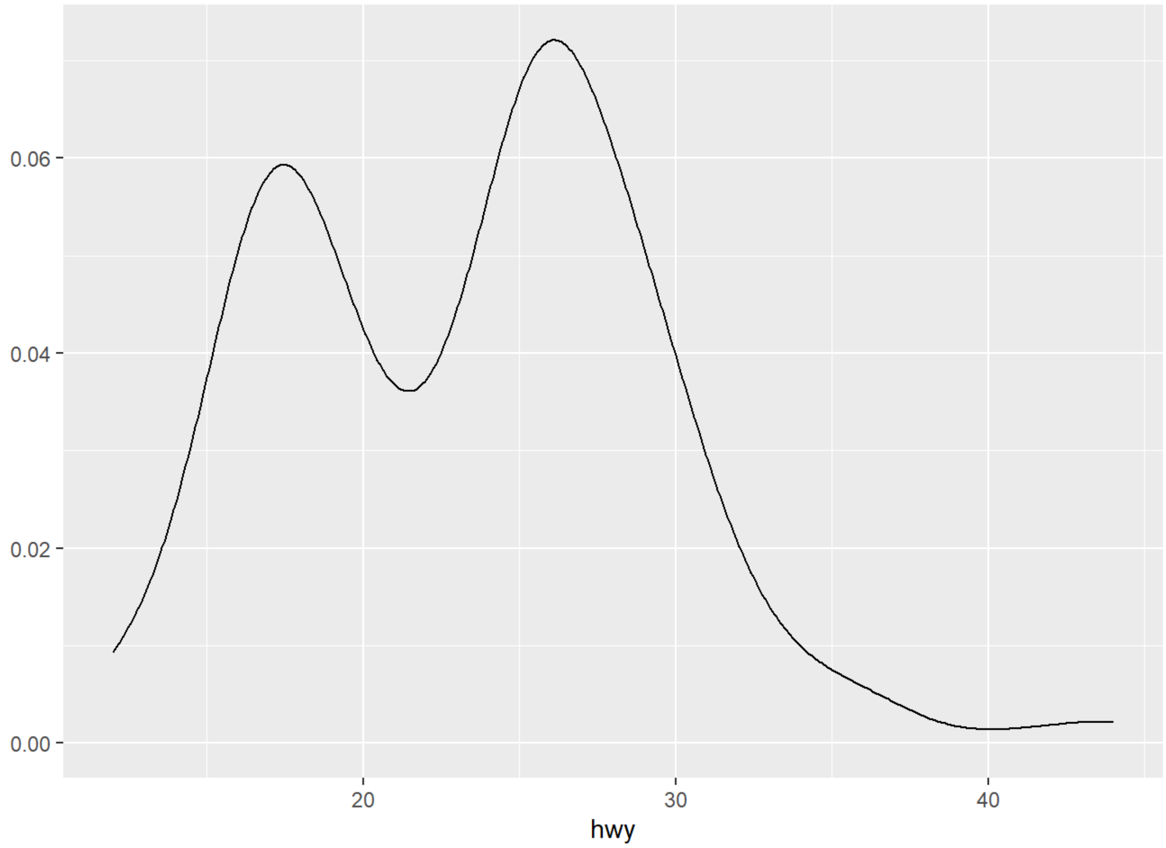
```
> qplot(hwy, data = mpg, facets = drv~., binwidth = 2)
```



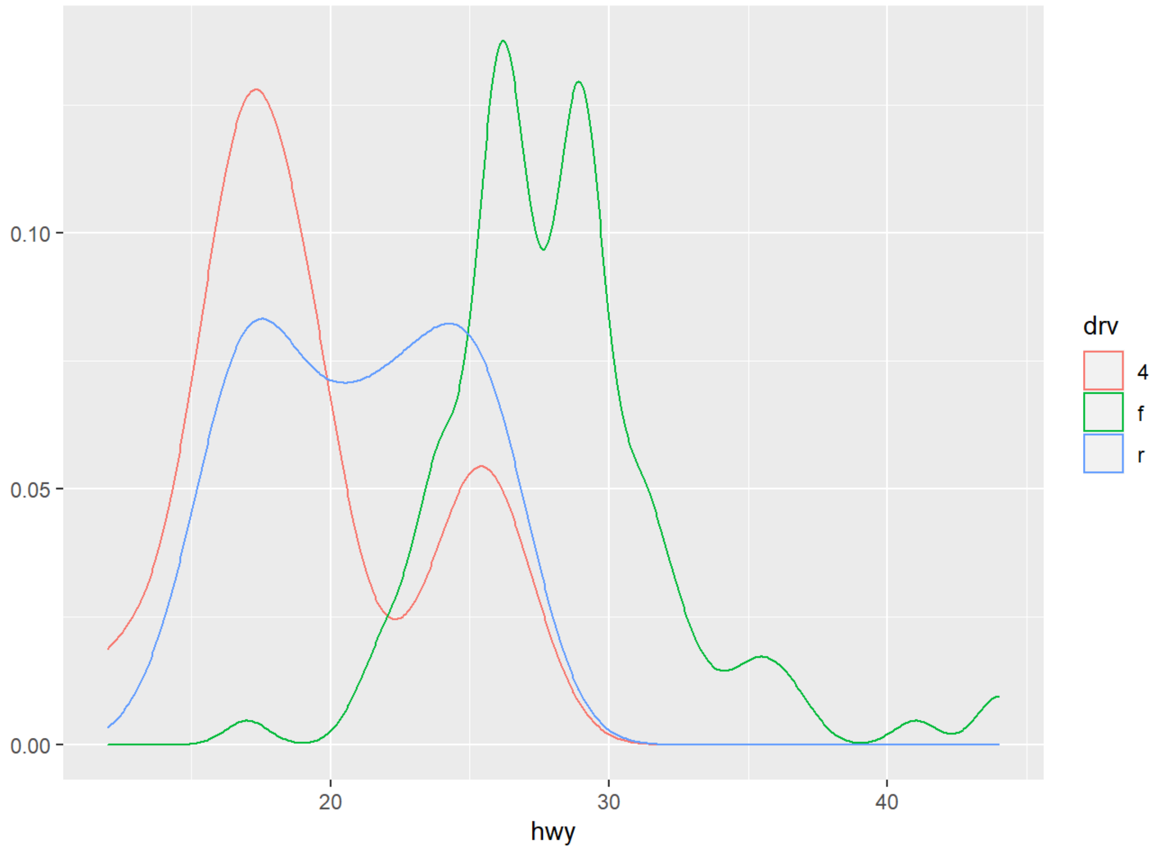

```
> qplot(displ, hwy, data = mpg, facets = .~drv)
```



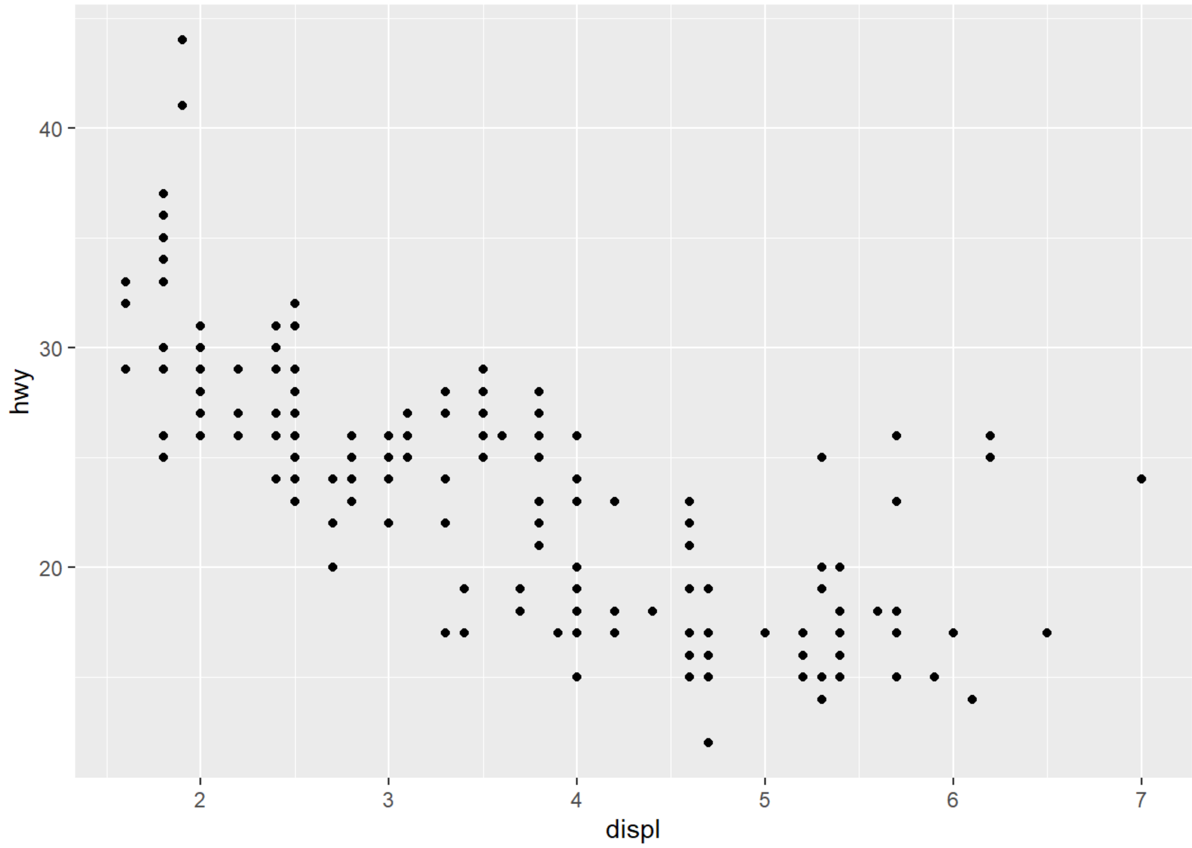
```
> qplot(hwy, data = mpg, geom = "density")
```



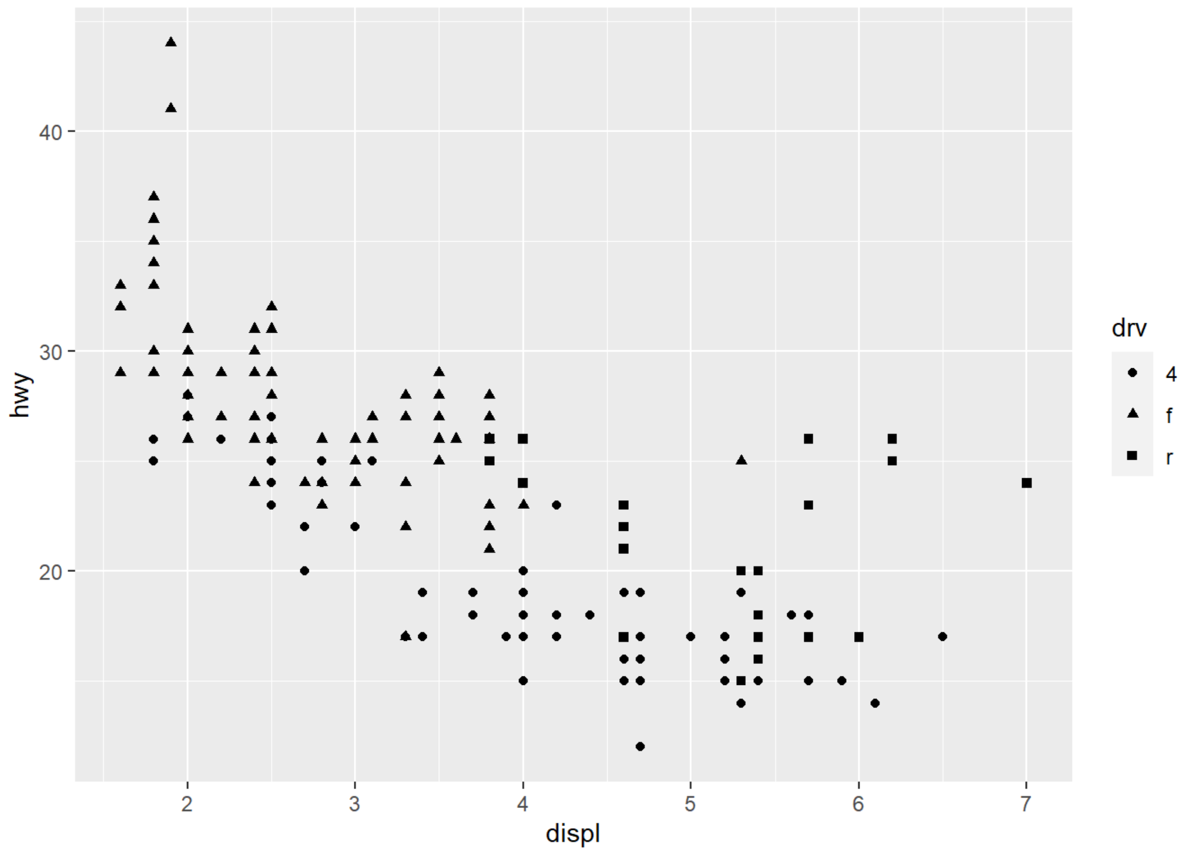

```
> qplot(hwy, data = mpg, geom = "density", color = drv)
```



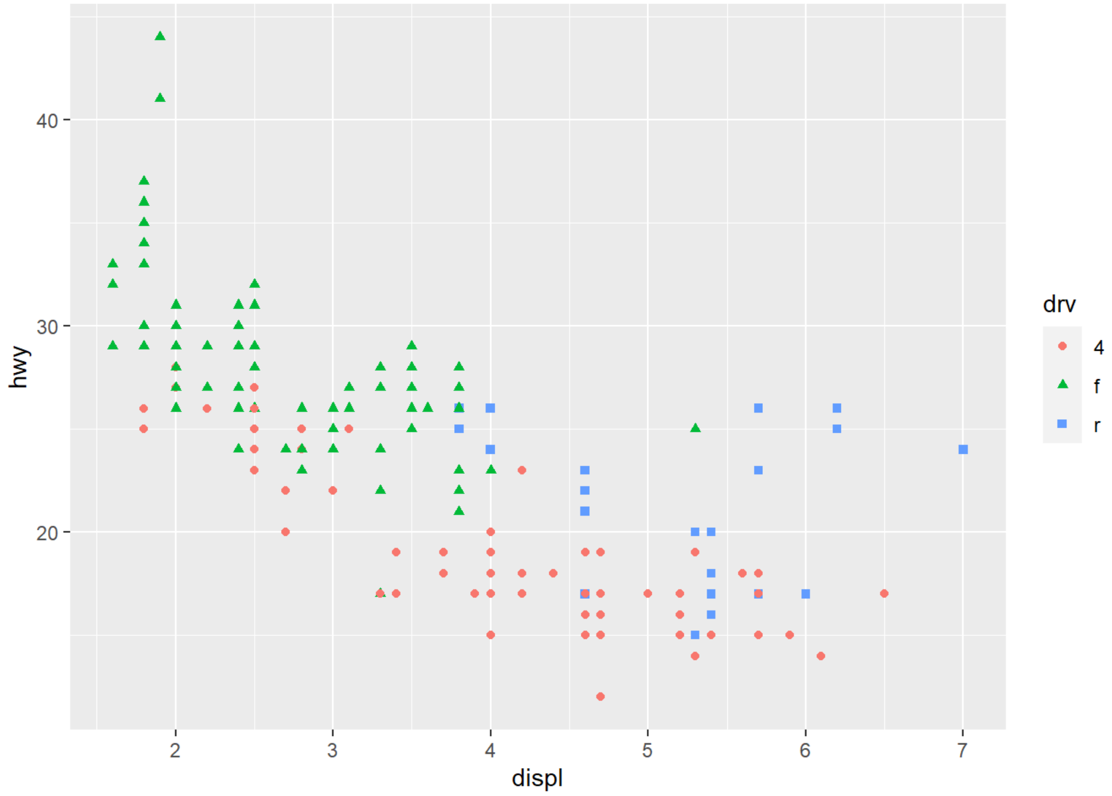
```
> qplot(displ, hwy, data = mpg)
```



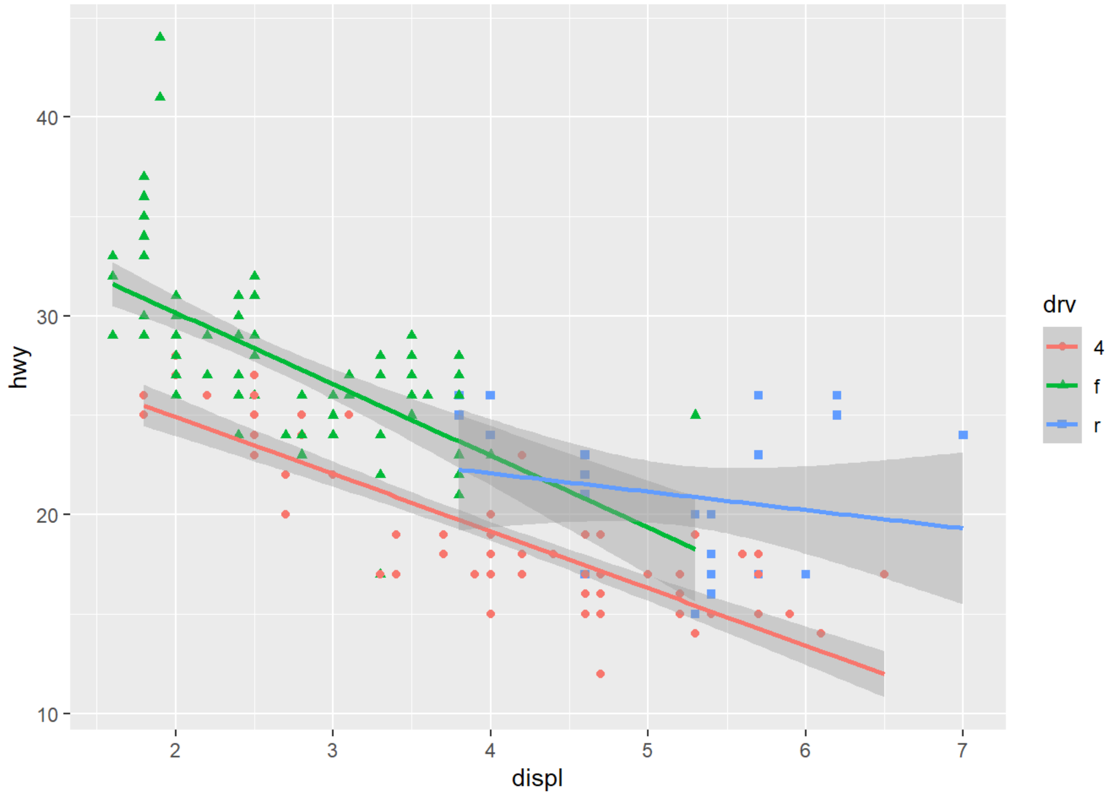

```
> qplot(displ, hwy, data = mpg, shape = drv)
```



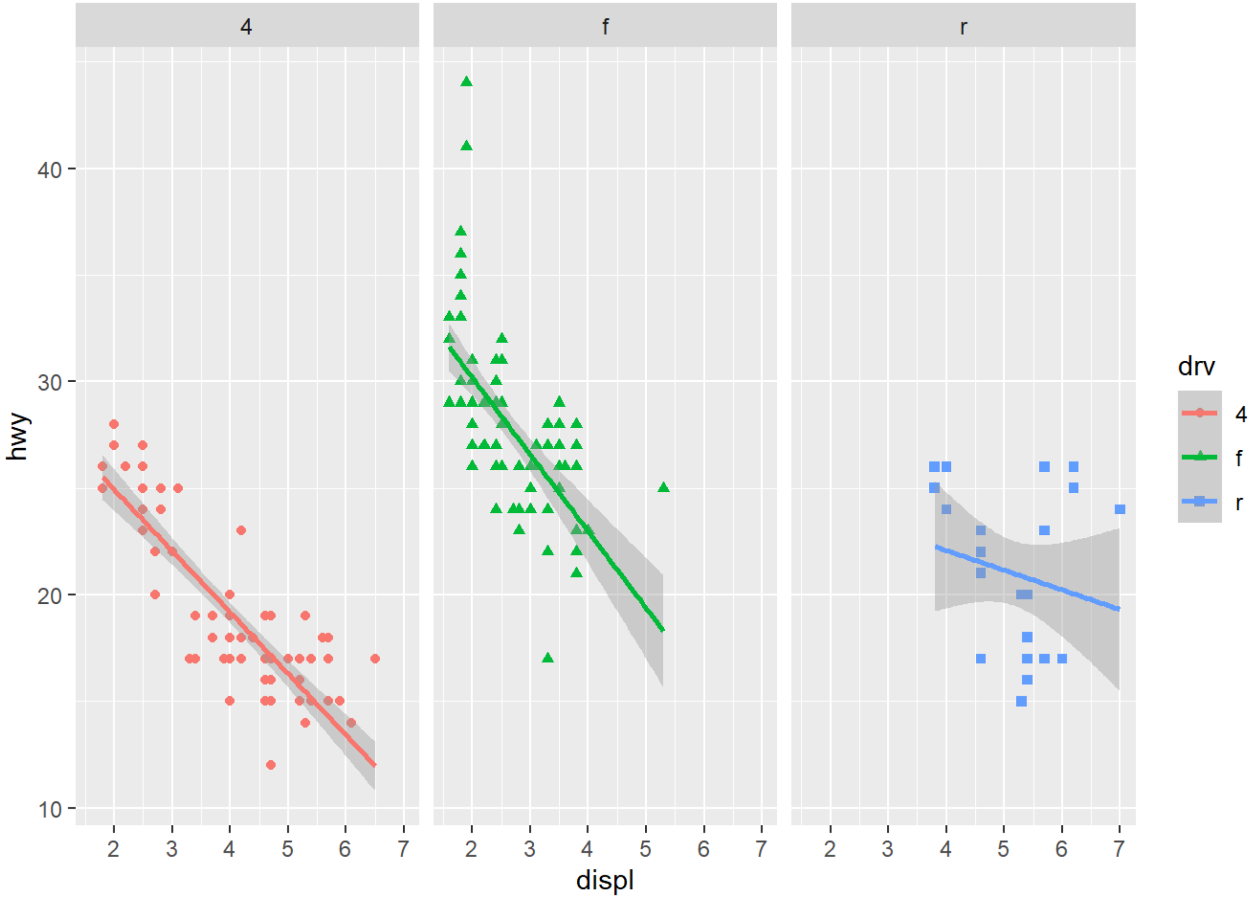
```
> qplot(displ, hwy, data = mpg, shape = drv, color = drv)
```




```
> qplot(displ, hwy, data = mpg, shape = drv, color = drv,
+         geom = c("point", "smooth"), method = "lm")
Warning: Ignoring unknown parameters: method
`geom_smooth()` using formula 'y ~ x'
```

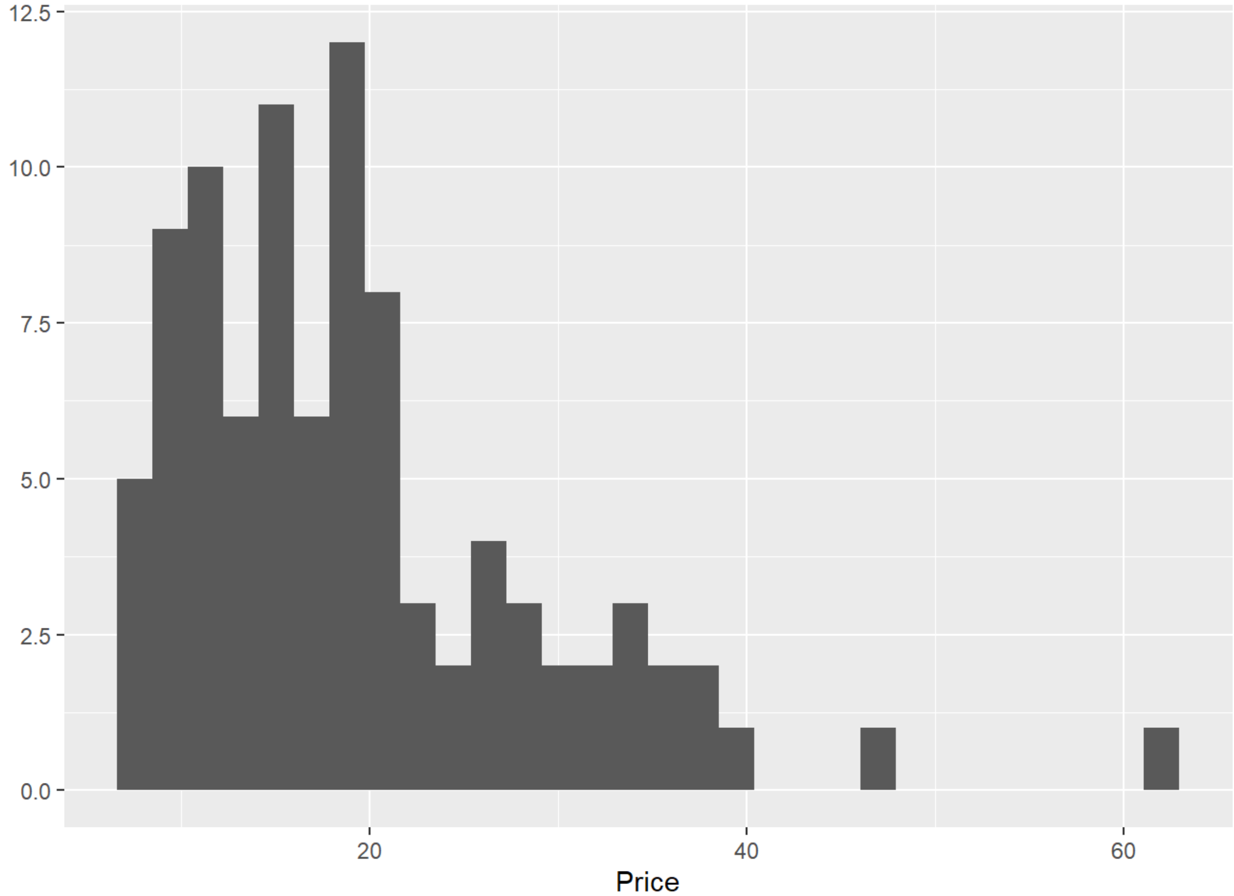


```
> qplot(displ, hwy, data = mpg, shape = drv, color = drv,
+        geom = c("point", "smooth"), method = "lm",
facets = .~drv)
Warning: Ignoring unknown parameters: method
`geom_smooth()` using formula 'y ~ x'
```

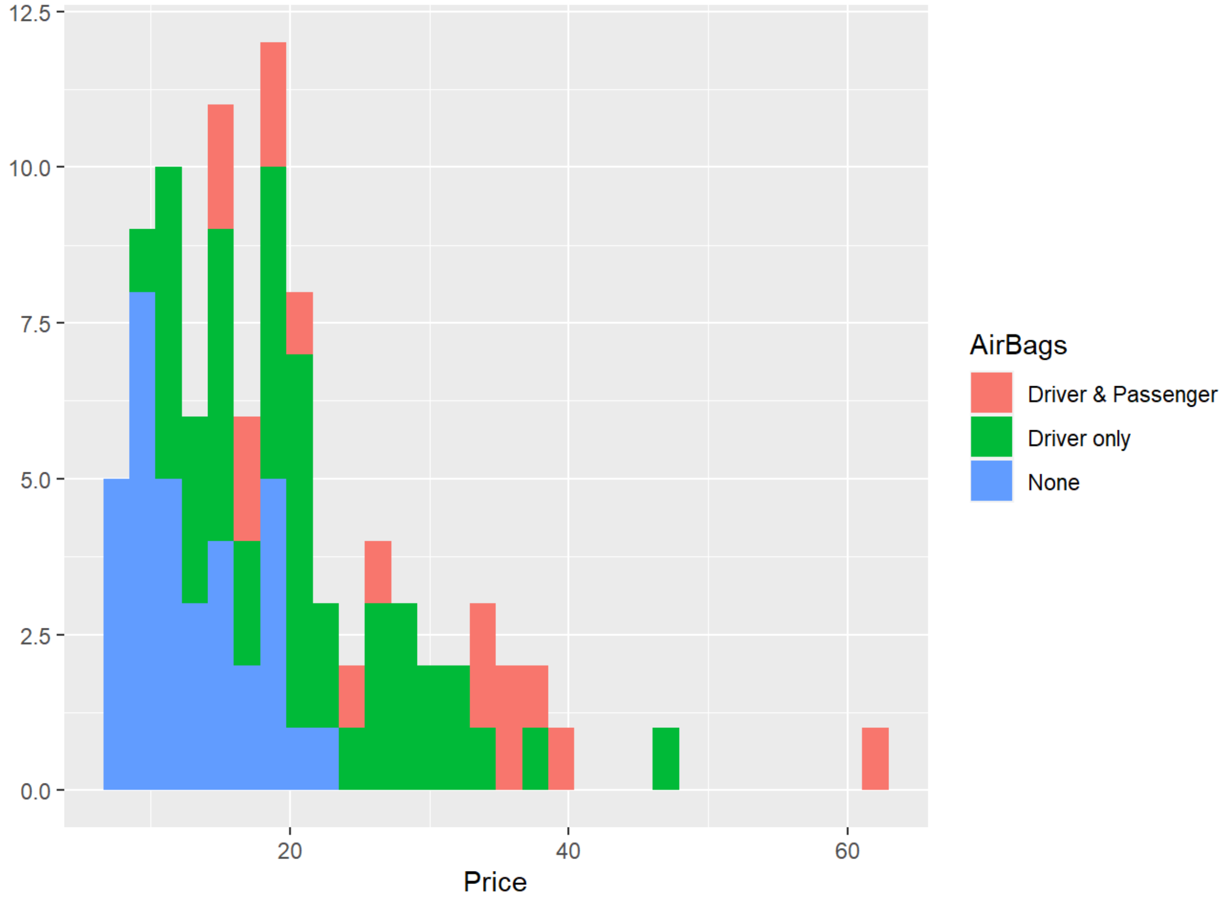


Using the `Cars93` data frame

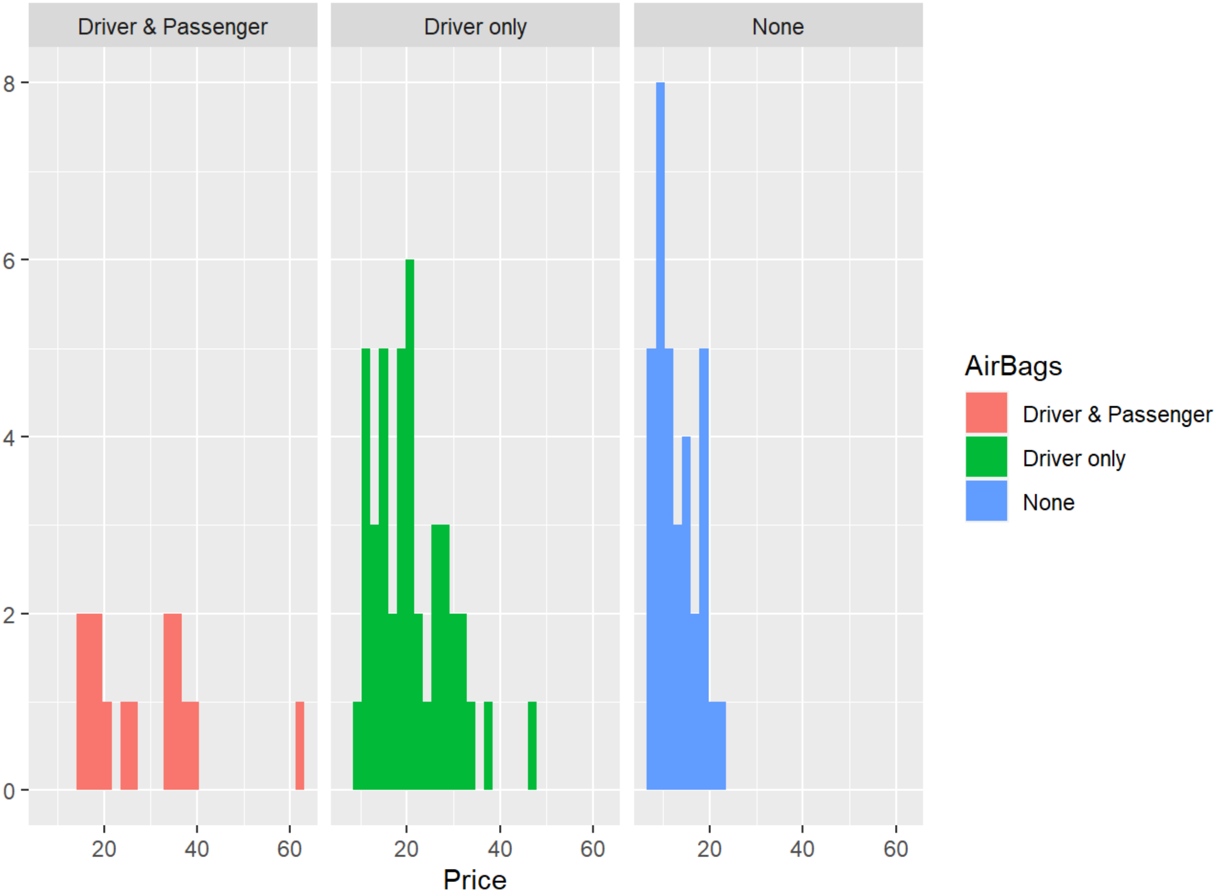
```
> qplot(Price, data = Cars93, geom= "histogram")
`stat_bin()` using `bins = 30`. Pick better value with
`binwidth`.
```



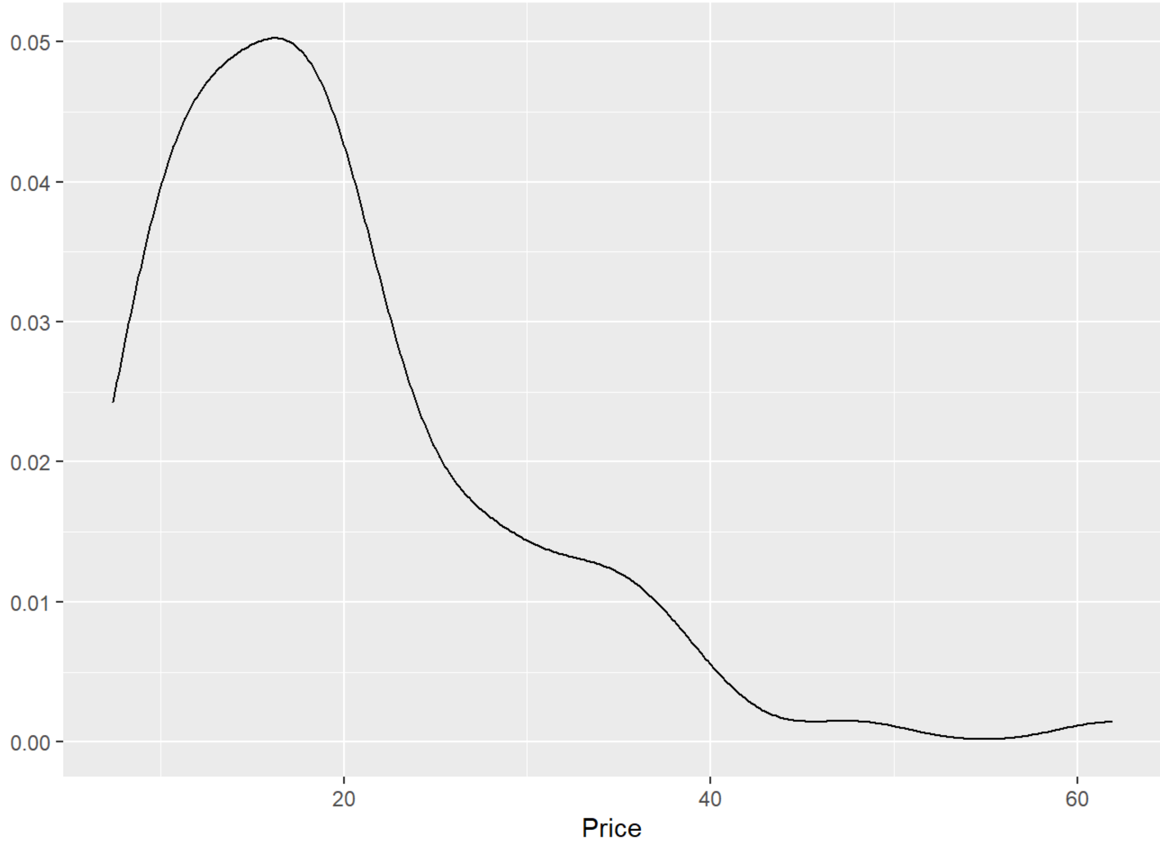
```
> qplot(Price, data = Cars93, geom= "histogram",
+         fill = AirBags)
`stat_bin()` using `bins = 30`. Pick better value with
`binwidth`.
```



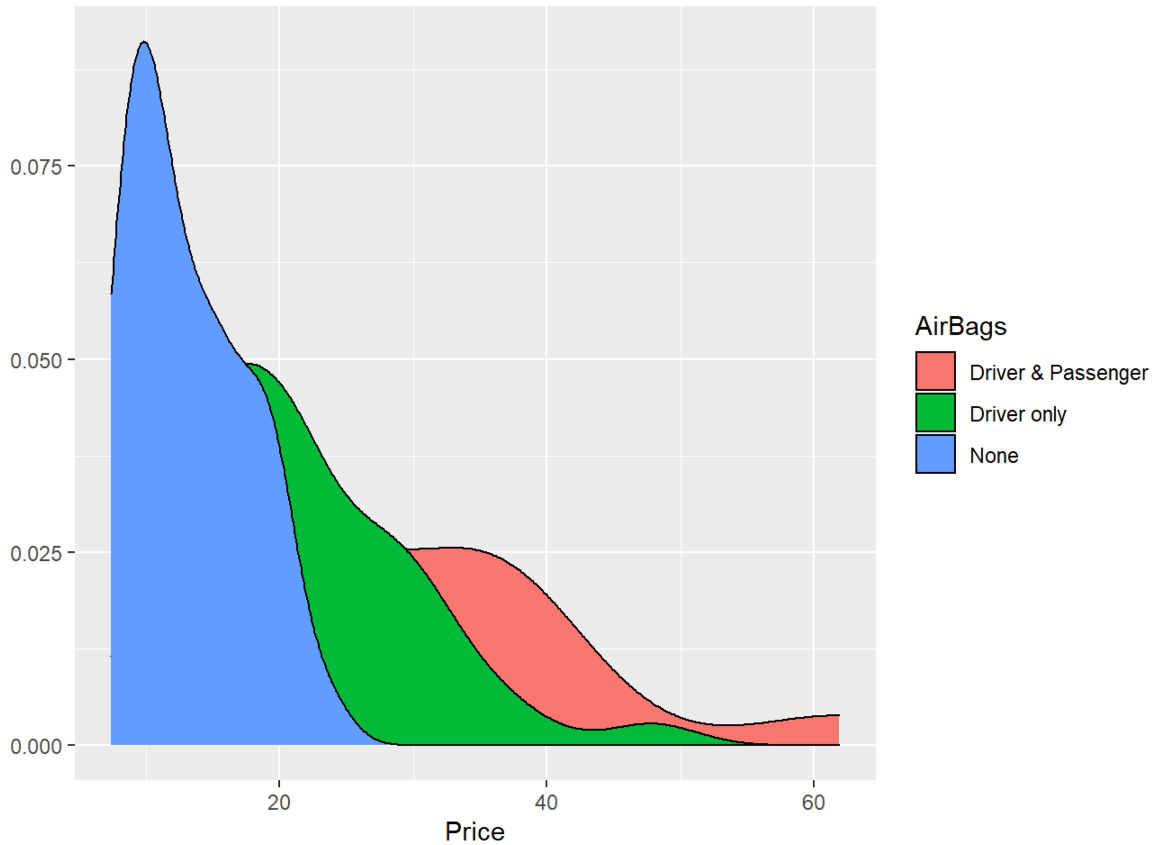
```
> qplot(Price, data = Cars93, geom= "histogram",
+       fill = AirBags, facets = .~AirBags)
`stat_bin()` using `bins = 30`. Pick better value with
`binwidth`.
```



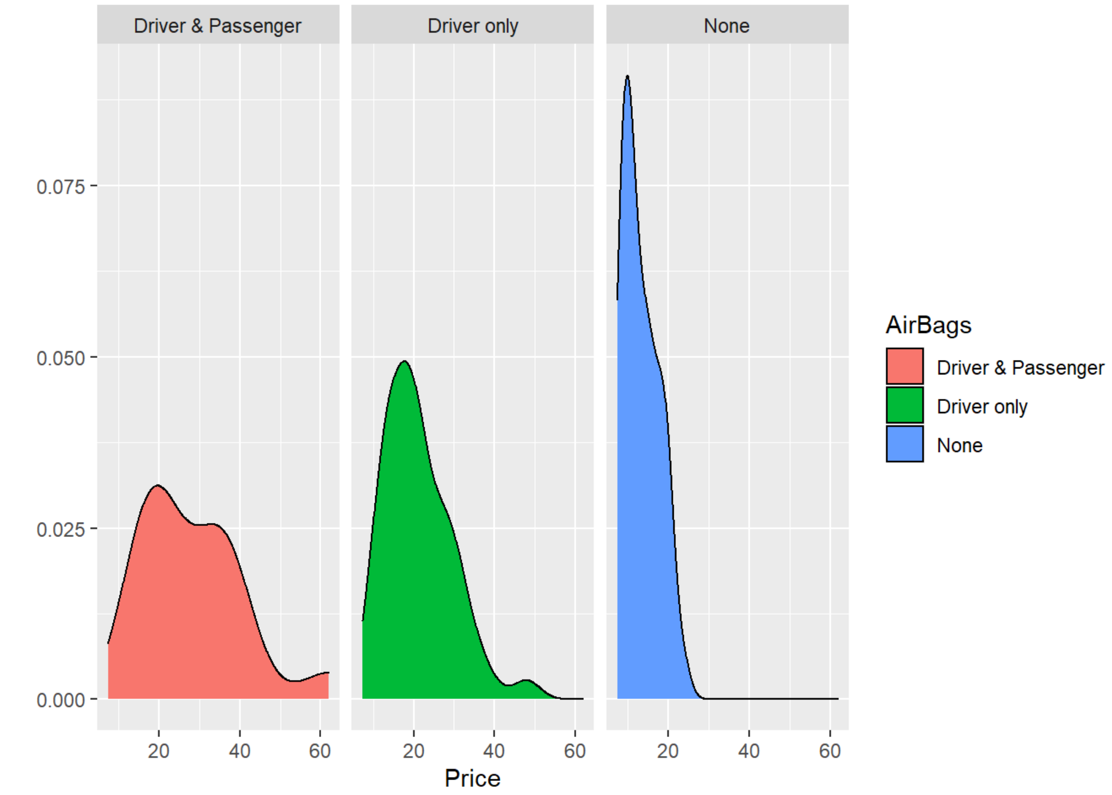
```
> qplot(Price, data = Cars93, geom= "density")
```




```
> qplot(Price, data = Cars93, geom= "density",
+        fill = AirBags)
```

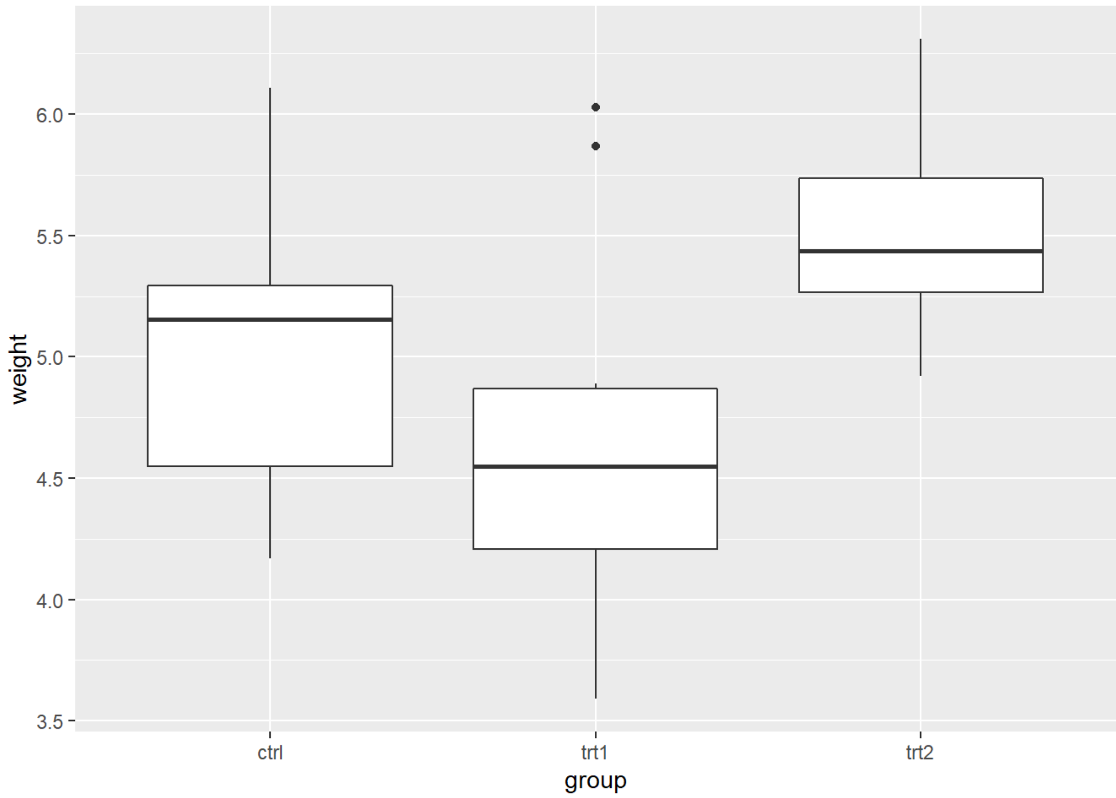


```
> qplot(Price, data = Cars93, geom= "density",
+         fill = AirBags, facets = .~AirBags)
```

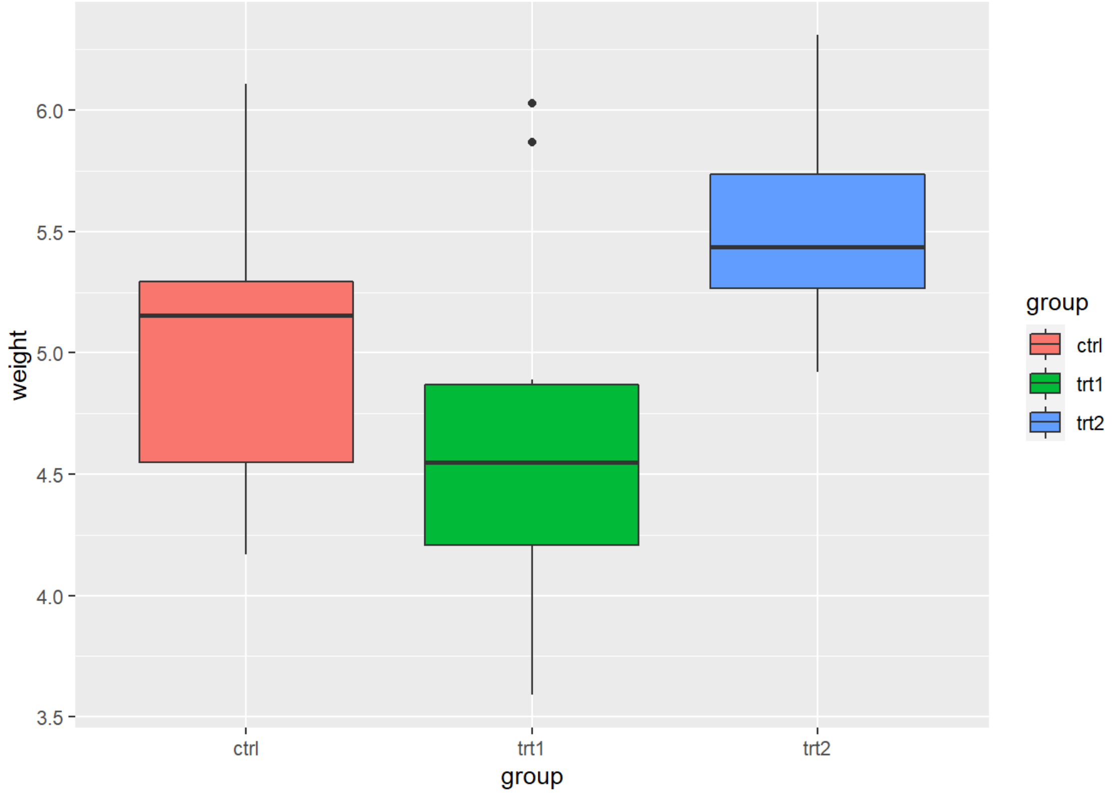


Boxplots from the `PlanthGrowth` example

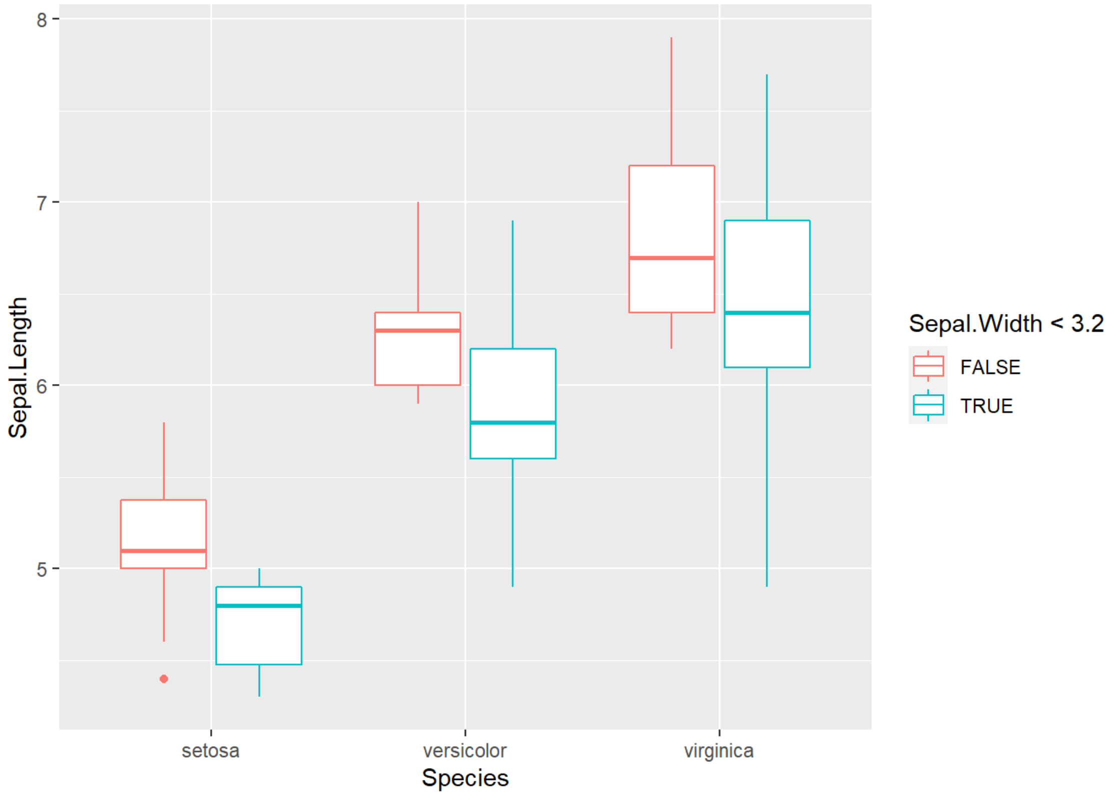
```
> qplot(group, weight, data = PlantGrowth, geom =
"boxplot")
```



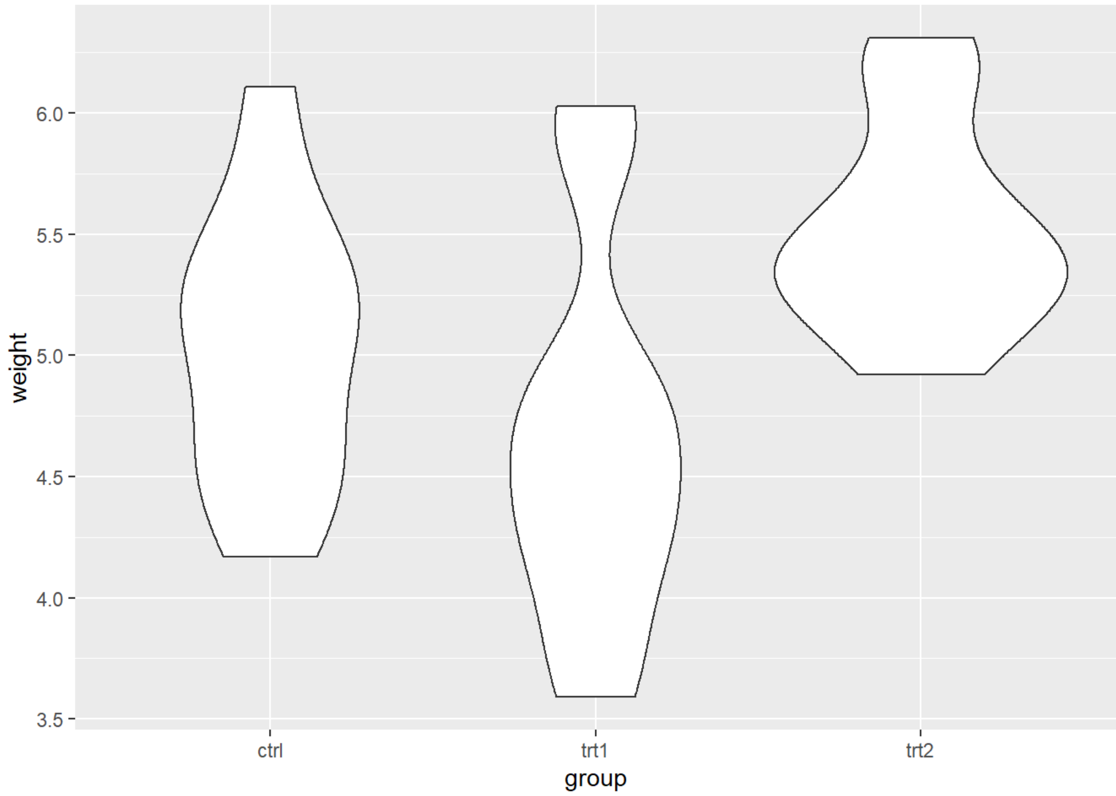
```
> qplot(group, weight, data = PlantGrowth, geom =
"boxplot",
+       fill = group)
```



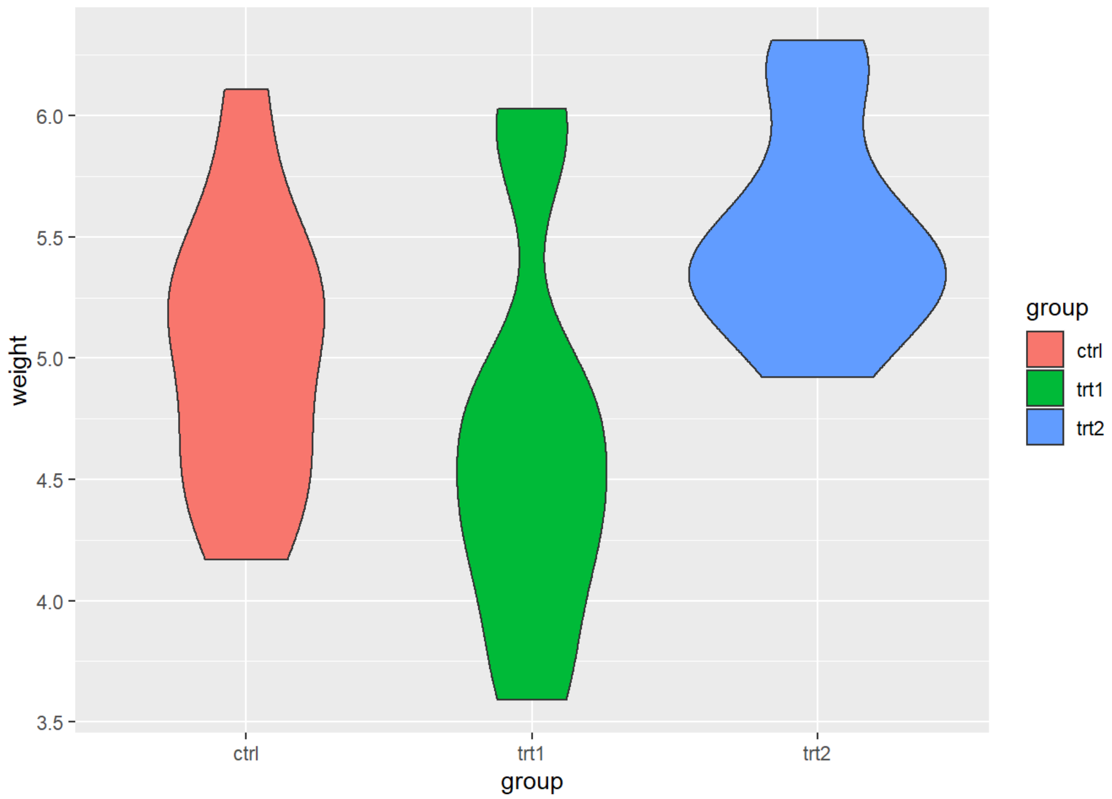

```
> ggplot(data = iris, aes(Species, Sepal.Length)) +
+   geom_boxplot(aes(colour = Sepal.Width < 3.2))
```



```
> qplot(group, weight, data = PlantGrowth, geom =
"violin")
```




```
> qplot(group, weight, data = PlantGrowth, geom =
"violin",
+       fill = group)
```



Let's review the prices of 50 000 diamonds from the `dimonds` data frame from `ggplot2` package, where `price` is the price of diamond in US dollars and cut is the quality of cut (Fair, Good, Very Good, Premium, Ideal). Make a frequency polygon for the prices depending on the cut quality.

```
> ggplot(diamonds, aes(price, colour = cut)) +
+   geom_freqpoly()
`stat_bin()` using `bins = 30`. Pick better value with
`binwidth`.
```