

ISLR 3: Linear Regression

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Load the following packages.

```
library(MASS)
library(ISLR)
```

Simple linear regression

Check out the Boston data

?Boston

```
names(Boston)
```

```
## [1] "crim"    "zn"      "indus"   "chas"    "nox"     "rm"      "age"
## [8] "dis"     "rad"     "tax"     "ptratio" "black"   "lstat"   "medv"
```

```
class(Boston)
```

```
## [1] "data.frame"
```

```
dim(Boston)
```

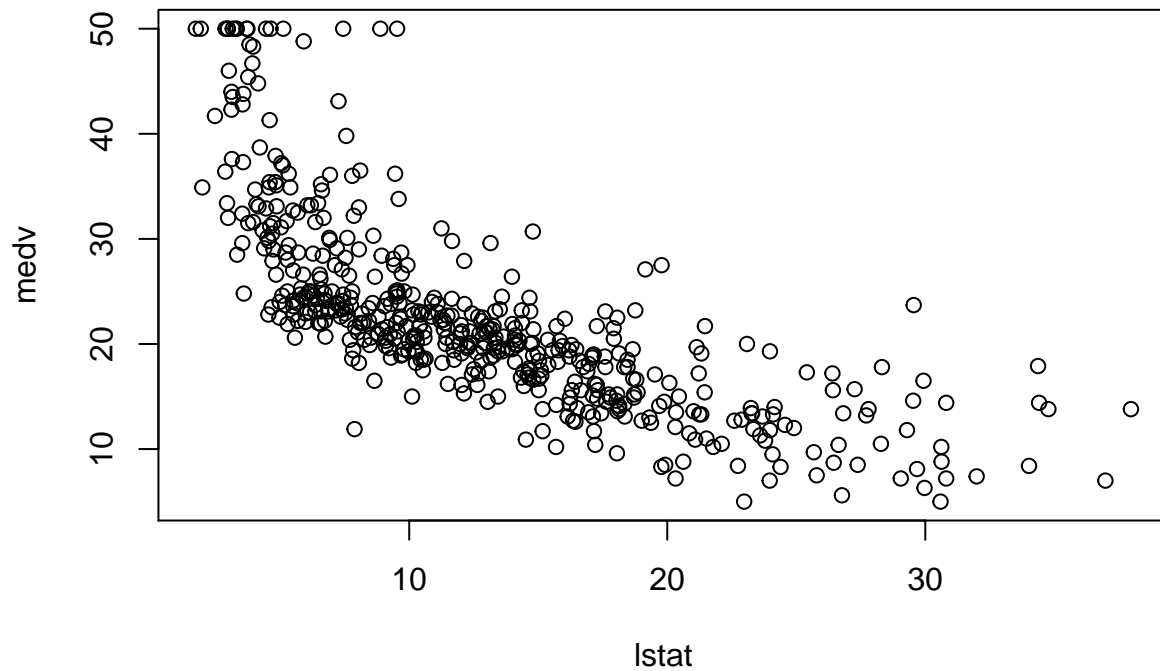
```
## [1] 506 14
```

```
summary(Boston)
```

```
##      crim              zn              indus              chas
## Min.   : 0.00632   Min.   : 0.00   Min.   : 0.46   Min.   :0.00000
## 1st Qu.: 0.08204   1st Qu.: 0.00   1st Qu.: 5.19   1st Qu.:0.00000
## Median : 0.25651   Median : 0.00   Median : 9.69   Median :0.00000
## Mean   : 3.61352   Mean   : 11.36   Mean   :11.14   Mean   :0.06917
## 3rd Qu.: 3.67708   3rd Qu.: 12.50   3rd Qu.:18.10   3rd Qu.:0.00000
## Max.   :88.97620   Max.   :100.00   Max.   :27.74   Max.   :1.00000
##      nox              rm              age              dis
## Min.   :0.3850   Min.   :3.561   Min.   : 2.90   Min.   : 1.130
## 1st Qu.:0.4490   1st Qu.:5.886   1st Qu.: 45.02   1st Qu.: 2.100
## Median :0.5380   Median :6.208   Median : 77.50   Median : 3.207
## Mean   :0.5547   Mean   :6.285   Mean   : 68.57   Mean   : 3.795
## 3rd Qu.:0.6240   3rd Qu.:6.623   3rd Qu.: 94.08   3rd Qu.: 5.188
## Max.   :0.8710   Max.   :8.780   Max.   :100.00   Max.   :12.127
##      rad              tax              ptratio              black
## Min.   : 1.000   Min.   :187.0   Min.   :12.60   Min.   : 0.32
## 1st Qu.: 4.000   1st Qu.:279.0   1st Qu.:17.40   1st Qu.:375.38
## Median : 5.000   Median :330.0   Median :19.05   Median :391.44
## Mean   : 9.549   Mean   :408.2   Mean   :18.46   Mean   :356.67
## 3rd Qu.:24.000   3rd Qu.:666.0   3rd Qu.:20.20   3rd Qu.:396.23
## Max.   :24.000   Max.   :711.0   Max.   :22.00   Max.   :396.90
##      lstat              medv
## Min.   : 1.73   Min.   : 5.00
## 1st Qu.: 6.95   1st Qu.:17.02
## Median :11.36   Median :21.20
## Mean   :12.65   Mean   :22.53
## 3rd Qu.:16.95   3rd Qu.:25.00
## Max.   :37.97   Max.   :50.00
```

Lets plot the Boston data

```
plot(medv ~ lstat, data = Boston)
```



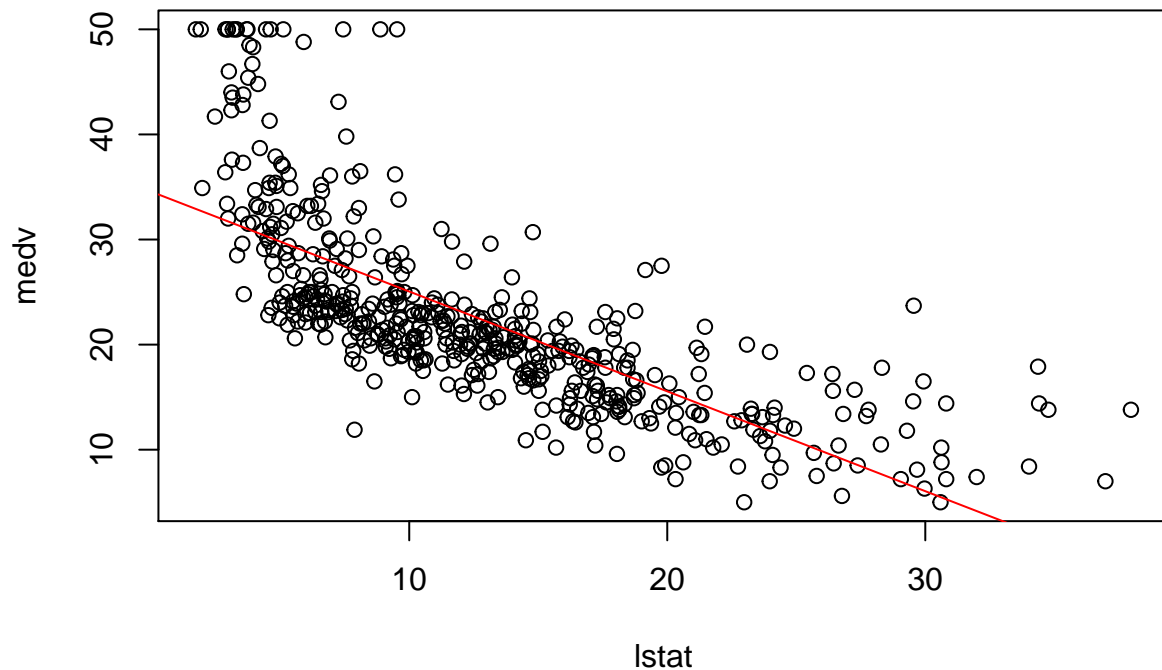
Run a linear model (lm) on it and print the results

```
Boston_lm <- lm(medv ~ lstat, data = Boston)
Boston_lm
```

```
##
## Call:
## lm(formula = medv ~ lstat, data = Boston)
##
## Coefficients:
## (Intercept)      lstat
##      34.55      -0.95
```

Lets plot the linear model against a scatter plot of medv and lstat.

```
plot(medv ~ lstat, data = Boston)
abline(Boston_lm, col="red")
```



We can check the confidence intervals of our models parameters using the `confint` function.

```
confint(Boston_lm)
```

```
##           2.5 %      97.5 %
## (Intercept) 33.448457 35.6592247
## lstat      -1.026148 -0.8739505
```

In addition, the `predict` function is useful in making some predictions with the `Boston_lm` model we created.

```
predict(Boston_lm, data.frame(lstat=c(5,10,15)), interval="confidence")
```

```
##      fit      lwr      upr
## 1 29.80359 29.00741 30.59978
## 2 25.05335 24.47413 25.63256
## 3 20.30310 19.73159 20.87461
```

Multiple linear regression

Regress `lstat` and `age` against `medv` of the Boston data set and print the `summary` diagnostics.

```
Boston_lm2 <- lm(medv ~ lstat + age, data = Boston)
summary(Boston_lm2)
```

```
##
## Call:
## lm(formula = medv ~ lstat + age, data = Boston)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -15.981  -3.978  -1.283   1.968  23.158
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  33.22276    0.73085  45.458 < 2e-16 ***
## lstat       -1.03207    0.04819 -21.416 < 2e-16 ***
## age          0.03454    0.01223   2.826  0.00491 **
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 6.173 on 503 degrees of freedom
## Multiple R-squared:  0.5513, Adjusted R-squared:  0.5495
## F-statistic: 309 on 2 and 503 DF, p-value: < 2.2e-16
```

Use the `.` notation to regress all variables in the Boston data against `medv` and print the `summary` diagnostics.

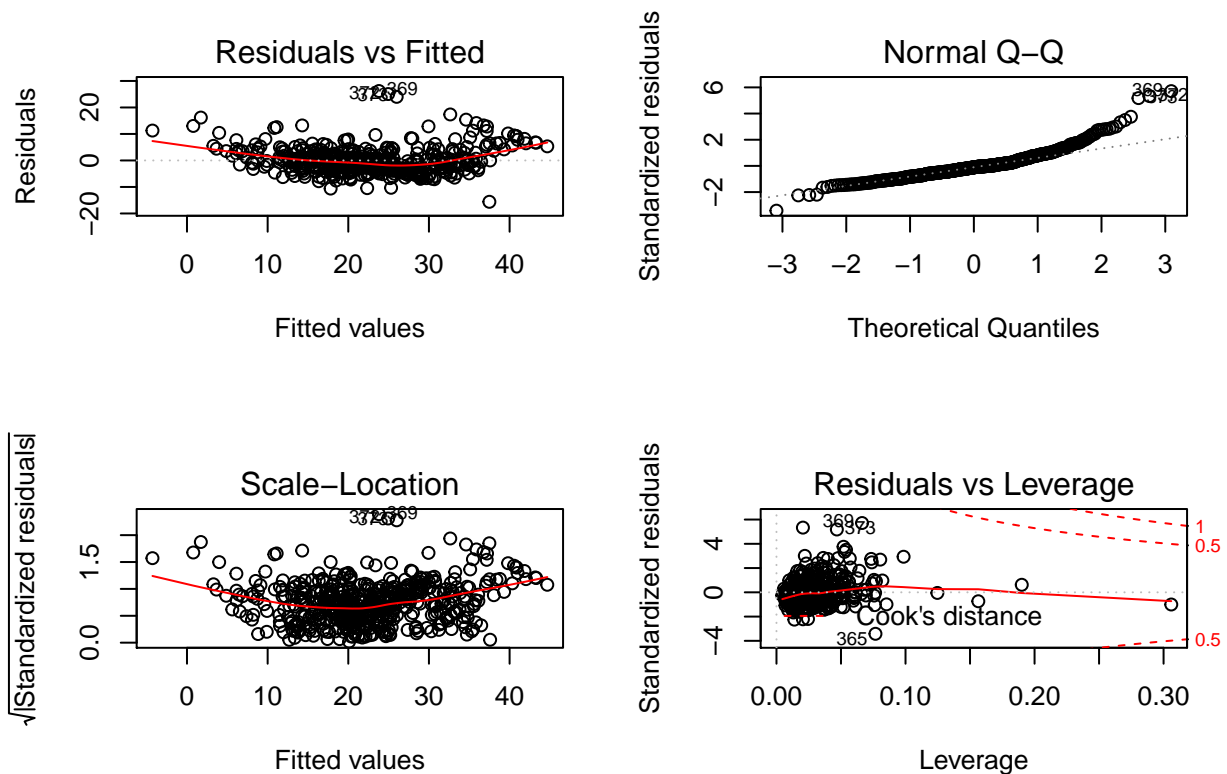
```
Boston_lm3 <- lm(medv ~ ., data = Boston)
summary(Boston_lm3)
```

```
##
## Call:
## lm(formula = medv ~ ., data = Boston)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -15.595  -2.730  -0.518   1.777  26.199
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)  3.646e+01  5.103e+00   7.144 3.28e-12 ***
## crim        -1.080e-01  3.286e-02  -3.287 0.001087 **
## zn           4.642e-02  1.373e-02   3.382 0.000778 ***
## indus        2.056e-02  6.150e-02   0.334 0.738288
## chas         2.687e+00  8.616e-01   3.118 0.001925 **
## nox         -1.777e+01  3.820e+00  -4.651 4.25e-06 ***
## rm           3.810e+00  4.179e-01   9.116 < 2e-16 ***
## age          6.922e-04  1.321e-02   0.052 0.958229
## dis         -1.476e+00  1.995e-01  -7.398 6.01e-13 ***
## rad          3.060e-01  6.635e-02   4.613 5.07e-06 ***
## tax         -1.233e-02  3.760e-03  -3.280 0.001112 **
## ptratio     -9.527e-01  1.308e-01  -7.283 1.31e-12 ***
## black        9.312e-03  2.686e-03   3.467 0.000573 ***
## lstat       -5.248e-01  5.072e-02 -10.347 < 2e-16 ***
```

```
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 4.745 on 492 degrees of freedom
## Multiple R-squared:  0.7406, Adjusted R-squared:  0.7338
## F-statistic: 108.1 on 13 and 492 DF,  p-value: < 2.2e-16
```

Lets plot the model

```
par(mfrow=c(2,2))
plot(Boston_lm3)
```



Use the `.` notation again to select all variables, but this time subtract `age` and `indus` before regressing against `medv`. Print the `summary` diagnostics.

```
Boston_lm4 <- update(Boston_lm3, ~.-age-indus)
summary(Boston_lm4)
```

```
##
## Call:
## lm(formula = medv ~ crim + zn + chas + nox + rm + dis + rad +
##      tax + ptratio + black + lstat, data = Boston)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -15.5984  -2.7386  -0.5046   1.7273  26.2373
##
## Coefficients:
```

```
##           Estimate Std. Error t value Pr(>|t|)
## (Intercept)  36.341145   5.067492   7.171 2.73e-12 ***
## crim        -0.108413   0.032779  -3.307 0.001010 **
## zn          0.045845   0.013523   3.390 0.000754 ***
## chas         2.718716   0.854240   3.183 0.001551 **
## nox        -17.376023   3.535243  -4.915 1.21e-06 ***
## rm           3.801579   0.406316   9.356 < 2e-16 ***
## dis         -1.492711   0.185731  -8.037 6.84e-15 ***
## rad           0.299608   0.063402   4.726 3.00e-06 ***
## tax         -0.011778   0.003372  -3.493 0.000521 ***
## ptratio     -0.946525   0.129066  -7.334 9.24e-13 ***
## black        0.009291   0.002674   3.475 0.000557 ***
## lstat       -0.522553   0.047424 -11.019 < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 4.736 on 494 degrees of freedom
## Multiple R-squared:  0.7406, Adjusted R-squared:  0.7348
## F-statistic: 128.2 on 11 and 494 DF,  p-value: < 2.2e-16
```

Nonlinear terms and Interactions

Multiply lstat by age and regress against medv:

```
Boston_mult <- lm(medv ~ lstat * age, data = Boston)
Boston_mult
```

```
##
## Call:
## lm(formula = medv ~ lstat * age, data = Boston)
##
## Coefficients:
## (Intercept)      lstat      age  lstat:age
##  36.0885359  -1.3921168  -0.0007209   0.0041560
```

Create a quadratic interaction using the I function with lstate:

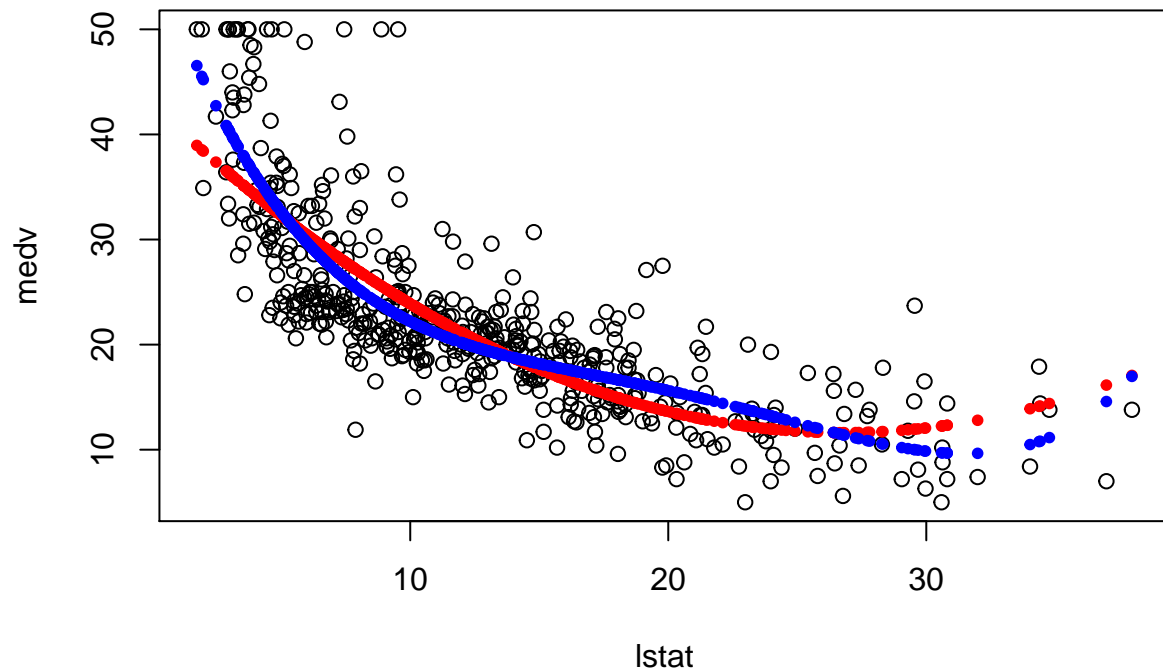
```
Boston_Interaction <- lm(medv ~ lstat + I(lstat^2), data = Boston)
```

Create a 4th order polynomial wrapping lstat in the poly function, defining the degree arguments a 4.

```
Boston_poly <- lm(medv ~ poly(lstat, degree=4), data = Boston)
```

Plot the results of the both the Boston_Interaction and Boston_poly models.

```
attach(Boston)
par(mfrow=c(1,1))
plot(medv ~ lstat, data = Boston)
points(lstat, fitted(Boston_Interaction), col="red", pch=20)
points(lstat, fitted(Boston_poly), col="blue", pch=20)
```



Finally, lets look at the coefficients of both:

Boston_Interaction

```
##
## Call:
## lm(formula = medv ~ lstat + I(lstat^2), data = Boston)
##
## Coefficients:
## (Intercept)      lstat      I(lstat^2)
##    42.86201    -2.33282     0.04355
```

Boston_poly

```
##
## Call:
## lm(formula = medv ~ poly(lstat, degree = 4), data = Boston)
##
## Coefficients:
## (Intercept) poly(lstat, degree = 4)1
##      22.53      -152.46
## poly(lstat, degree = 4)2 poly(lstat, degree = 4)3
##      64.23      -27.05
## poly(lstat, degree = 4)4
##      25.45
```


Qualitative predictors

For this section, use the `Carseats` data. Lets explore:

```
?Carseats
```

```
names(Carseats)
```

```
## [1] "Sales"      "CompPrice"  "Income"     "Advertising" "Population"
## [6] "Price"      "ShelveLoc"  "Age"        "Education"   "Urban"
## [11] "US"
```

```
summary(Carseats)
```

```
##      Sales      CompPrice      Income      Advertising
## Min.   : 0.000   Min.   : 77   Min.   : 21.00   Min.   : 0.000
## 1st Qu.: 5.390   1st Qu.:115   1st Qu.: 42.75   1st Qu.: 0.000
## Median : 7.490   Median :125   Median : 69.00   Median : 5.000
## Mean   : 7.496   Mean   :125   Mean   : 68.66   Mean   : 6.635
## 3rd Qu.: 9.320   3rd Qu.:135   3rd Qu.: 91.00   3rd Qu.:12.000
## Max.   :16.270   Max.   :175   Max.   :120.00   Max.   :29.000
##      Population      Price      ShelveLoc      Age
## Min.   : 10.0   Min.   : 24.0   Bad   : 96   Min.   :25.00
## 1st Qu.:139.0   1st Qu.:100.0   Good  : 85   1st Qu.:39.75
## Median :272.0   Median :117.0   Medium:219   Median :54.50
## Mean   :264.8   Mean   :115.8               Mean   :53.32
## 3rd Qu.:398.5   3rd Qu.:131.0               3rd Qu.:66.00
## Max.   :509.0   Max.   :191.0               Max.   :80.00
##      Education      Urban      US
## Min.   :10.0   No :118   No :142
## 1st Qu.:12.0   Yes:282   Yes:258
## Median :14.0
## Mean   :13.9
## 3rd Qu.:16.0
## Max.   :18.0
```

Run a model regressing all variables as well as two new interactive variables resulting from combining `Income:Advertising` and `Age:Price`.

```
Carseats_lm <- lm(Sales ~. + Income:Advertising + Age:Price, data = Carseats)
summary(Carseats_lm)
```

```
##
## Call:
## lm(formula = Sales ~ . + Income:Advertising + Age:Price, data = Carseats)
##
## Residuals:
##      Min       1Q   Median       3Q      Max
## -2.9208 -0.7503  0.0177  0.6754  3.3413
##
## Coefficients:
##              Estimate Std. Error t value Pr(>|t|)
## (Intercept)    6.5755654   1.0087470    6.519 2.22e-10 ***
## CompPrice      0.0929371   0.0041183   22.567 < 2e-16 ***
## Income         0.0108940   0.0026044    4.183 3.57e-05 ***
## Advertising    0.0702462   0.0226091    3.107 0.002030 **
## Population     0.0001592   0.0003679    0.433 0.665330
##
```

```
## Price          -0.1008064  0.0074399 -13.549 < 2e-16 ***
## ShelveLocGood   4.8486762  0.1528378  31.724 < 2e-16 ***
## ShelveLocMedium 1.9532620  0.1257682  15.531 < 2e-16 ***
## Age            -0.0579466  0.0159506  -3.633 0.000318 ***
## Education      -0.0208525  0.0196131  -1.063 0.288361
## UrbanYes       0.1401597  0.1124019   1.247 0.213171
## USYes          -0.1575571  0.1489234  -1.058 0.290729
## Income:Advertising 0.0007510  0.0002784   2.698 0.007290 **
## Price:Age       0.0001068  0.0001333   0.801 0.423812
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 1.011 on 386 degrees of freedom
## Multiple R-squared:  0.8761, Adjusted R-squared:  0.8719
## F-statistic: 210 on 13 and 386 DF, p-value: < 2.2e-16
```

Call the `contrasts` function on the `ShelveLoc` variable to display a table of levels corresponding to the quality of the shelving location for the car seats at each site.

```
contrasts(Carseats$ShelveLoc)
```

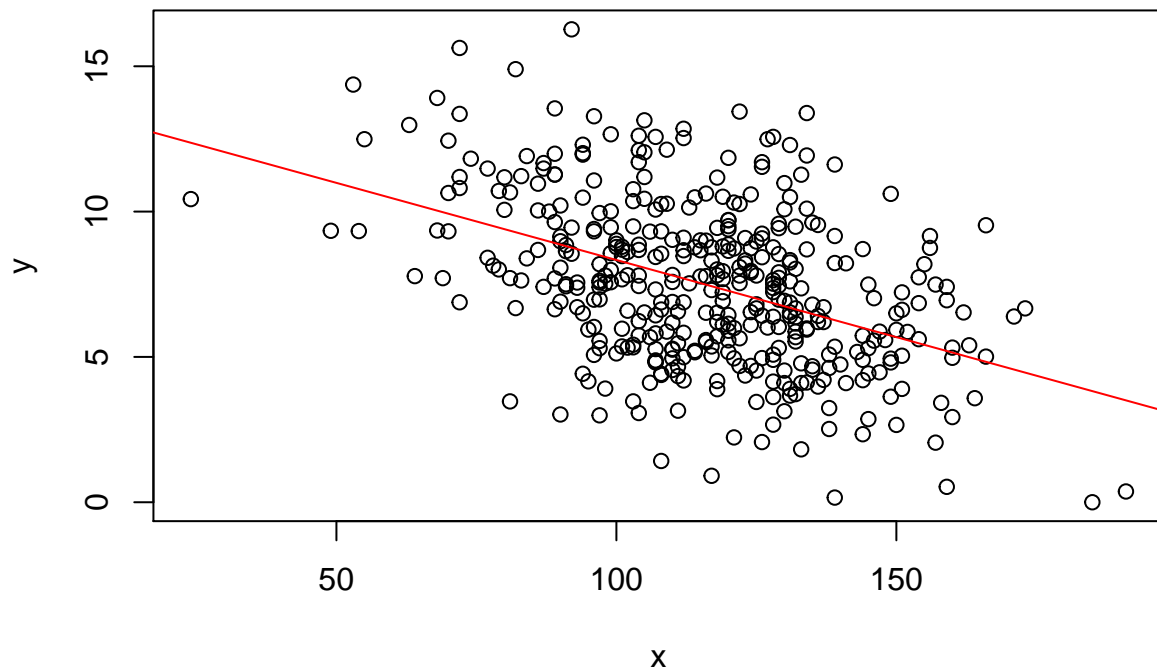
```
##           Good Medium
## Bad           0      0
## Good          1      0
## Medium        0      1
```

Brief section writing R functions

Function creating a plot which displays linear model regression line.

```
regplot <- function(x, y){
  fit <- lm(y ~ x)
  plot(x, y)
  abline(fit, col="red")
}

attach(Carseats)
regplot(Price, Sales)
```



This time, add the ... argument to the function, which allowing one to pass arguments to functions within the function.

```
regplot <- function(x, y, ...){  
  fit <- lm(y ~ x)  
  plot(x, y, ...)  
  abline(fit, col="red")  
}  
  
regplot(Price, Sales, xlab="Price", ylab="Sales", col="blue", pch=20)
```

