Task 21

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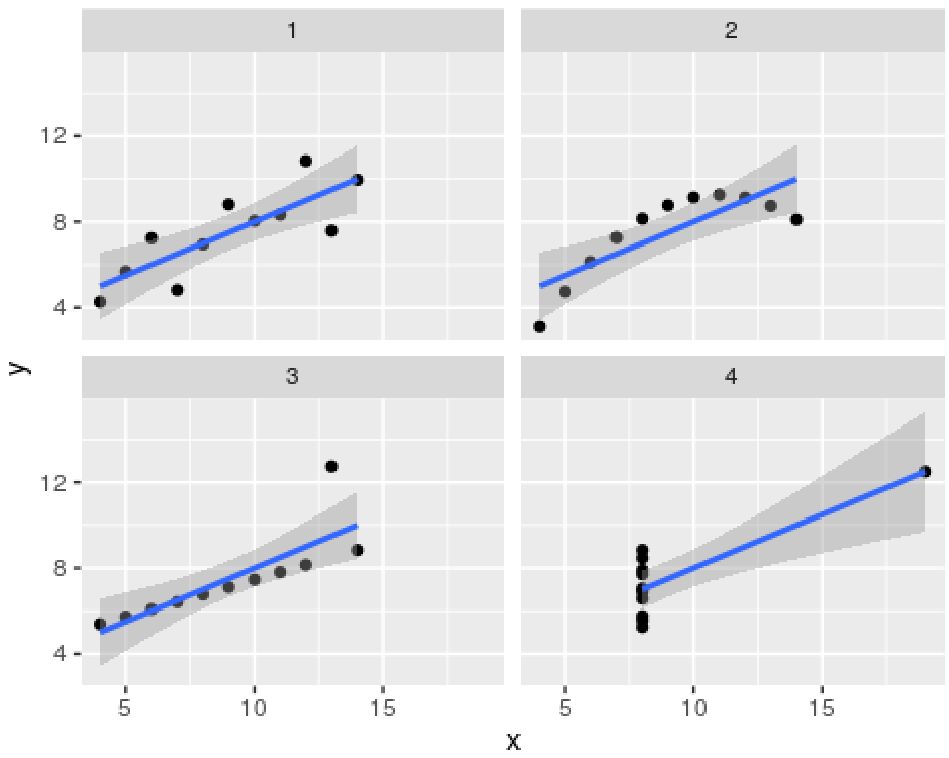
```
library('ggplot2')
library('ggpubr')
library('dplyr')
library('tidyr')
library('broom')
library('lubridate')
library('reshape2')
```

Statistics in R: task1

Ancomb dataset

1) Scatter plot facetted by set + the 95% confidence level interval for predictions from a linear model

```
# make data long

df_long <- anscombe %>%
   mutate(index = 1:nrow(anscombe)) %>%
   gather(key, value, -index) %>%
   separate(key, c("var", "set"), 1, convert = TRUE)  %>%
   spread(var, value)%>%
   select(-index)

# plot with lm line
ggplot(df_long,aes(x,y,group=set))+
  geom_point()+
  stat_smooth(method="lm")+
  facet_wrap(~set)
```



2) Summary by set

```
by(df_long[,2:3], df_long$set, summary)
```

```
## df_long$set: 1
##        x              y         
##  Min.   : 4.0   Min.   : 4.260  
##  1st Qu.: 6.5   1st Qu.: 6.315  
##  Median : 9.0   Median : 7.580  
##  Mean   : 9.0   Mean   : 7.501  
##  3rd Qu.:11.5   3rd Qu.: 8.570  
##  Max.   :14.0   Max.   :10.840  
## ------------------------------------------------------------ 
## df_long$set: 2
##        x              y        
##  Min.   : 4.0   Min.   :3.100  
##  1st Qu.: 6.5   1st Qu.:6.695  
##  Median : 9.0   Median :8.140  
##  Mean   : 9.0   Mean   :7.501  
##  3rd Qu.:11.5   3rd Qu.:8.950  
##  Max.   :14.0   Max.   :9.260  
## ------------------------------------------------------------ 
## df_long$set: 3
##        x              y        
##  Min.   : 4.0   Min.   : 5.39  
##  1st Qu.: 6.5   1st Qu.: 6.25  
##  Median : 9.0   Median : 7.11  
##  Mean   : 9.0   Mean   : 7.50  
##  3rd Qu.:11.5   3rd Qu.: 7.98  
##  Max.   :14.0   Max.   :12.74  
## -------------------------------------------------------- 
## df_long$set: 4
##        x            y         
##  Min.   : 8   Min.   : 5.250  
##  1st Qu.: 8   1st Qu.: 6.170  
##  Median : 8   Median : 7.040  
##  Mean   : 9   Mean   : 7.501  
##  3rd Qu.: 8   3rd Qu.: 8.190  
##  Max.   :19   Max.   :12.500
```

3) Correlation betveen x and y in each set. Parametric and non-parametric tests.

```
pearson <- df_long %>%
  group_by(set) %>%
  do(tidy(cor.test(.$x, .$y, method='pearson')))

spearman <- df_long %>%
  group_by(set) %>%
  do(tidy(cor.test(.$x, .$y, method='spearman')))

df_cor <- data.frame(pearson$estimate, pearson$p.value,
spearman$estimate, spearman$p.value)
df_cor
```

```
##   pearson.estimate pearson.p.value spearman.estimate spearman.p.value
## 1        0.8164205     0.002169629         0.8181818      0.003734471
## 2        0.8162365     0.002178816         0.6909091      0.023058874
## 3        0.8162867     0.002176305         0.9909091      0.000000000
## 4        0.8165214     0.002164602         0.5000000      0.117306803
```

Air quality dataset

1) Clean dataset

```
# read
df <- read.csv("./AirQualityUCI.csv", stringsAsFactors = FALSE, sep = ';')

# examine the data structure
str(df)
```

```
## 'data.frame':    9471 obs. of  17 variables:
##  $ Date         : chr  "10/03/2004" "10/03/2004" "10/03/2004" "10/03/2004" 
...
##  $ Time         : chr  "18.00.00" "19.00.00" "20.00.00" "21.00.00" ...
##  $ CO.GT.       : chr  "2,6" "2" "2,2" "2,2" ...
##  $ PT08.S1.CO.  : int  1360 1292 1402 1376 1272 1197 1185 1136 1094 
1010 ...
##  $ NMHC.GT.     : int  150 112 88 80 51 38 31 31 24 19 ...
##  $ C6H6.GT.     : chr  "11,9" "9,4" "9,0" "9,2" ...
##  $ PT08.S2.NMHC.: int  1046 955 939 948 836 750 690 672 609 561 ...
##  $ NOx.GT.      : int  166 103 131 172 131 89 62 62 45 -200 ...
##  $ PT08.S3.NOx. : int  1056 1174 1140 1092 1205 1337 1462 1453 1579 1705 ...
##  $ NO2.GT.      : int  113 92 114 122 116 96 77 76 60 -200 ...
##  $ PT08.S4.NO2. : int  1692 1559 1555 1584 1490 1393 1333 1333 1276 1235 ...
##  $ PT08.S5.O3.  : int  1268 972 1074 1203 1110 949 733 730 620 501 ...
##  $ T            : chr  "13,6" "13,3" "11,9" "11,0" ...
##  $ RH           : chr  "48,9" "47,7" "54,0" "60,0" ...
##  $ AH           : chr  "0,7578" "0,7255" "0,7502" "0,7867" ...
##  $ X            : logi  NA NA NA NA NA NA ...
##  $ X.1          : logi  NA NA NA NA NA NA ...
```

```
# convert date and time to special type
df$date_time = dmy_hms(paste(df$Date, df$Time))

# remove unuseful cols
df <- df[,c(3:15,18) ]

# chr to numeric
char_columns <- sapply(df, is.character)
df[ , char_columns] <- lapply(df[ , char_columns] , function(x) as.numeric(gsub(",", ".", x)))

# explore summary
summary(df)
```

```
##      CO.GT.         PT08.S1.CO.      NMHC.GT.         C6H6.GT.      
##  Min.   :-200.00   Min.   :-200   Min.   :-200.0   Min.   :-200.000  
##  1st Qu.:   0.60   1st Qu.: 921   1st Qu.:-200.0   1st Qu.:   4.000  
##  Median :   1.50   Median :1053   Median :-200.0   Median :   7.900  
##  Mean   : -34.21   Mean   :1049   Mean   :-159.1   Mean   :   1.866  
##  3rd Qu.:   2.60   3rd Qu.:1221   3rd Qu.:-200.0   3rd Qu.:  13.600  
##  Max.   :  11.90   Max.   :2040   Max.   :1189.0   Max.   :  63.700  
##  NA's   :114       NA's   :114    NA's   :114      NA's   :114       
##  PT08.S2.NMHC.       NOx.GT.        PT08.S3.NOx.      NO2.GT.      
##  Min.   :-200.0   Min.   :-200.0   Min.   :-200   Min.   :-200.00  
##  1st Qu.: 711.0   1st Qu.:  50.0   1st Qu.: 637   1st Qu.:  53.00  
##  Median : 895.0   Median : 141.0   Median : 794   Median :  96.00  
##  Mean   : 894.6   Mean   : 168.6   Mean   : 795   Mean   :  58.15  
##  3rd Qu.:1105.0   3rd Qu.: 284.0   3rd Qu.: 960   3rd Qu.: 133.00  
##  Max.   :2214.0   Max.   :1479.0   Max.   :2683   Max.   : 340.00  
##  NA's   :114      NA's   :114      NA's   :114    NA's   :114      
##   PT08.S4.NO2.   PT08.S5.O3.           T                  RH        
##  Min.   :-200   Min.   :-200.0   Min.   :-200.000   Min.   :-200.00  
##  1st Qu.:1185   1st Qu.: 700.0   1st Qu.:  10.900   1st Qu.:  34.10  
##  Median :1446   Median : 942.0   Median :  17.200   Median :  48.60  
##  Mean   :1391   Mean   : 975.1   Mean   :   9.778   Mean   :  39.49  
##  3rd Qu.:1662   3rd Qu.:1255.0   3rd Qu.:  24.100   3rd Qu.:  61.90  
##  Max.   :2775   Max.   :2523.0   Max.   :  44.600   Max.   :  88.70  
##  NA's   :114    NA's   :114      NA's   :114        NA's   :114      
##        AH              date_time
##  Min.   :-200.0000   Min.   :2004-03-10 18:00:00
##  1st Qu.:   0.6923   1st Qu.:2004-06-16 05:00:00
##  Median :   0.9768   Median :2004-09-21 16:00:00
##  Mean   :  -6.8376   Mean   :2004-09-21 16:00:00
##  3rd Qu.:   1.2962   3rd Qu.:2004-12-28 03:00:00
##  Max.   :   2.2310   Max.   :2005-04-04 14:00:00
##  NA's   :114         NA's   :114
```

```
head(df)
```

```
##   CO.GT. PT08.S1.CO. NMHC.GT. C6H6.GT. PT08.S2.NMHC. NOx.GT.
PT08.S3.NOx.
## 1    2.6        1360      150     11.9          1046     166         1056
## 2    2.0        1292      112      9.4           955     103         1174
## 3    2.2        1402       88      9.0           939     131         1140
## 4    2.2        1376       80      9.2           948     172         1092
## 5    1.6        1272       51      6.5           836     131         1205
## 6    1.2        1197       38      4.7           750      89         1337
##   NO2.GT. PT08.S4.NO2. PT08.S5.O3.    T   RH     AH           date_time
## 1     113         1692        1268 13.6 48.9 0.7578 2004-03-10 18:00:00
## 2      92         1559         972 13.3 47.7 0.7255 2004-03-10 19:00:00
## 3     114         1555        1074 11.9 54.0 0.7502 2004-03-10 20:00:00
## 4     122         1584        1203 11.0 60.0 0.7867 2004-03-10 21:00:00
## 5     116         1490        1110 11.2 59.6 0.7888 2004-03-10 22:00:00
## 6      96         1393         949 11.2 59.2 0.7848 2004-03-10 23:00:00
```

```
# remove na
df <- na.omit(df)

# value -200 is suspicious
# let values -200 be NA
df_no200 <- df[, 1:13]
df_no200[] <- sapply(df[, 1:13] , function(x) {x[grep("-200", x)] = NA;
return((x))})
str(df_no200)
```

```
## 'data.frame':    9357 obs. of  13 variables:
##  $ CO.GT.       : num  2.6 2 2.2 2.2 1.6 1.2 1.2 1 0.9 0.6 ...
##  $ PT08.S1.CO.  : num  1360 1292 1402 1376 1272 ...
##  $ NMHC.GT.     : num  150 112 88 80 51 38 31 31 24 19 ...
##  $ C6H6.GT.     : num  11.9 9.4 9 9.2 6.5 4.7 3.6 3.3 2.3 1.7 ...
##  $ PT08.S2.NMHC.: num  1046 955 939 948 836 ...
##  $ NOx.GT.      : num  166 103 131 172 131 89 62 62 45 NA ...
##  $ PT08.S3.NOx. : num  1056 1174 1140 1092 1205 ...
##  $ NO2.GT.      : num  113 92 114 122 116 96 77 76 60 NA ...
##  $ PT08.S4.NO2. : num  1692 1559 1555 1584 1490 ...
##  $ PT08.S5.O3.  : num  1268 972 1074 1203 1110 ...
##  $ T            : num  13.6 13.3 11.9 11 11.2 11.2 11.3 10.7 10.7 10.3 ...
##  $ RH           : num  48.9 47.7 54 60 59.6 59.2 56.8 60 59.7 60.2 ...
##  $ AH           : num  0.758 0.726 0.75 0.787 0.789 ...
```

```
# replace na with median
df_named <- replace(df_no200, TRUE, lapply(df_no200, function(x) replace(x,
is.na(x), median(x, na.rm = TRUE))))

# new summary without outliers
summary(df_named)
```

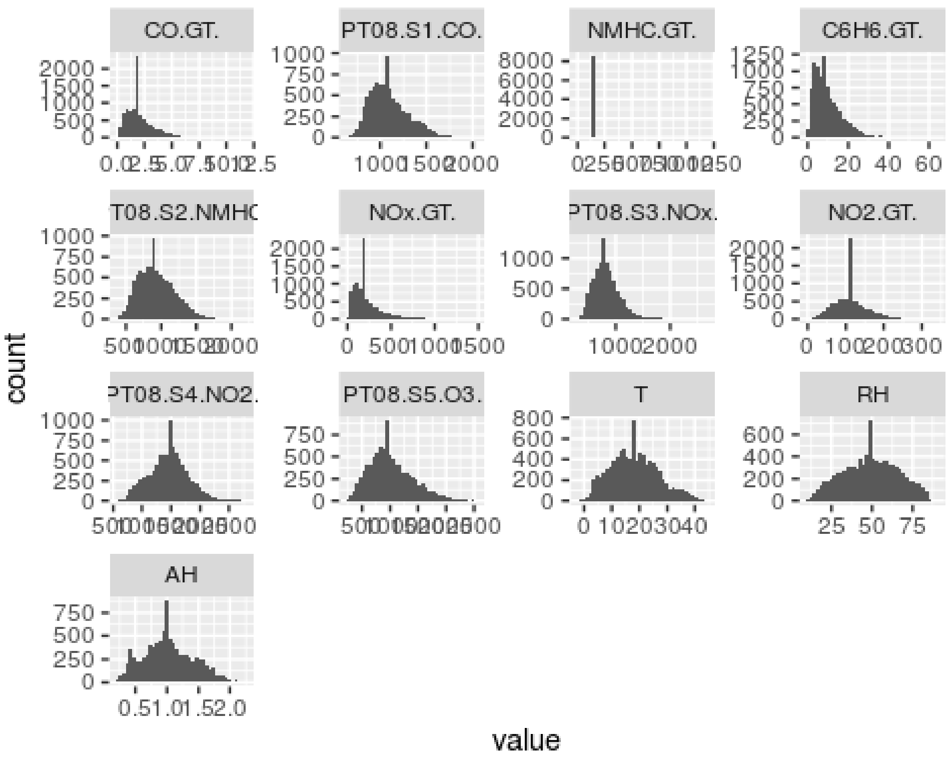
```
##      CO.GT.        PT08.S1.CO.      NMHC.GT.         C6H6.GT.    
##  Min.   : 0.100   Min.   : 647   Min.   :   7.0   Min.   : 0.10  
##  1st Qu.: 1.200   1st Qu.: 941   1st Qu.: 150.0   1st Qu.: 4.60  
##  Median : 1.800   Median :1063   Median : 150.0   Median : 8.20  
##  Mean   : 2.089   Mean   :1098   Mean   : 156.7   Mean   :10.01  
##  3rd Qu.: 2.600   3rd Qu.:1221   3rd Qu.: 150.0   3rd Qu.:13.60  
##  Max.   :11.900   Max.   :2040   Max.   :1189.0   Max.   :63.70  
##  PT08.S2.NMHC.     NOx.GT.        PT08.S3.NOx.       NO2.GT.     
##  Min.   : 383   Min.   :   2.0   Min.   : 322.0   Min.   :  2.0  
##  1st Qu.: 743   1st Qu.: 112.0   1st Qu.: 666.0   1st Qu.: 86.0  
##  Median : 909   Median : 180.0   Median : 806.0   Median :109.0  
##  Mean   : 938   Mean   : 235.2   Mean   : 834.3   Mean   :112.4  
##  3rd Qu.:1105   3rd Qu.: 284.0   3rd Qu.: 960.0   3rd Qu.:133.0  
##  Max.   :2214   Max.   :1479.0   Max.   :2683.0   Max.   :340.0  
##   PT08.S4.NO2.   PT08.S5.O3.         T               RH              AH        
##  Min.   : 551   Min.   : 221   Min.   :-1.9   Min.   : 9.20   Min.   :0.1847  
##  1st Qu.:1242   1st Qu.: 742   1st Qu.:12.0   1st Qu.:36.60   1st Qu.:0.7461  

##  Median :1463   Median : 963   Median :17.8   Median :49.60   Median :
0.9954  
##  Mean   :1457   Mean   :1021   Mean   :18.3   Mean   :49.25   Mean   :
1.0244  
##  3rd Qu.:1662   3rd Qu.:1255   3rd Qu.:24.1   3rd Qu.:61.90   3rd
Qu.:1.2962  
##  Max.   :2775   Max.   :2523   Max.   :44.6   Max.   :88.70   Max.   :2.2310  
```

```
# adding date_time column
df_named$date_time <- df$date_time
```

2) Explore columns

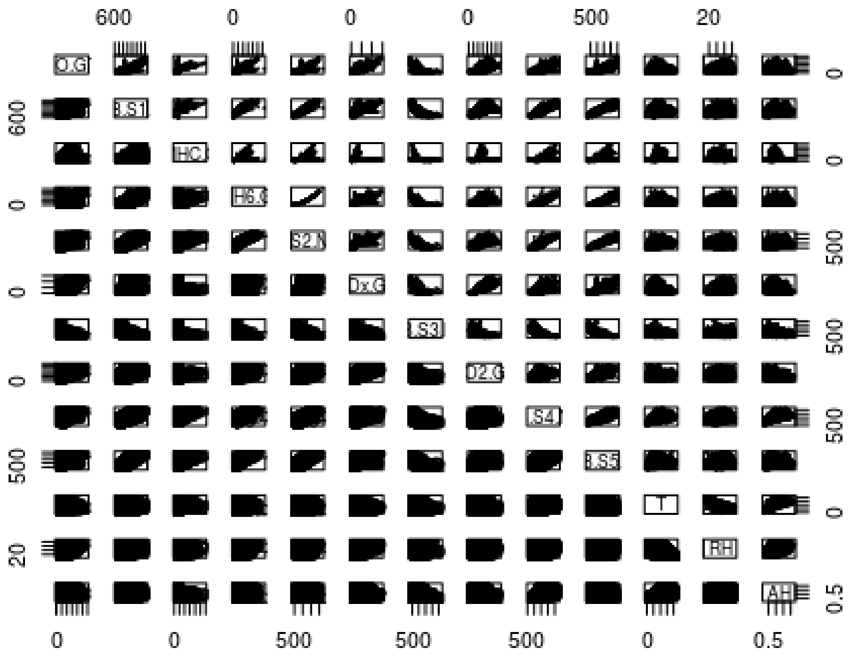
As we can see, probably it wasn`t a good idea to replace outliers with median, because there was to many of them. We also can see, that not all variables has normal distribution. This can bias the linear regression analysis

```
df_named%>%
  mutate(id=c(1:nrow(df_named)))%>%
  melt(measure.vars=c(1:13))->long

ggplot(long, aes(value)) +
  geom_histogram(bins=40) +
  facet_wrap(~variable, scales = "free")
```



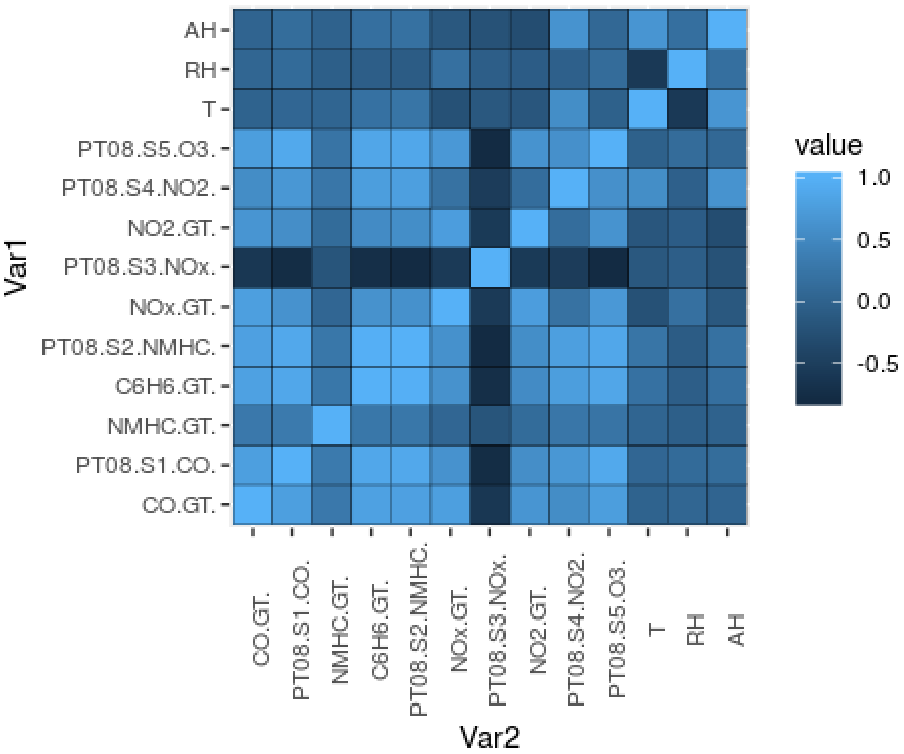
3) Let`s discovery cross-correlations

```
# plot correlations
panel.points<-function(x,y)
{
  points(x,y,cex=.01)
}

pairs(df_named[, 1:13], upper.panel = panel.points)
```



```
# correlation heatmap - more comportable way to find cross-correlations
cor_mtx <- (cor(df_named[,1:13]))

# all correlations in mtx
cor_mtx

##                     CO.GT. PT08.S1.CO.    NMHC.GT.    C6H6.GT. PT08.S2.NMHC.
## CO.GT.        1.000000000  0.77694776  0.29105348  0.80885654
0.79595937
## PT08.S1.CO.    0.776947756  1.00000000  0.30612962  0.88387075
0.89298861
## NMHC.GT.       0.291053479  0.30612962  1.00000000  0.27042800
0.26807390
## C6H6.GT.       0.808856543  0.88387075  0.27042800  1.00000000
0.98159631
## PT08.S2.NMHC.  0.795959375  0.89298861  0.26807390  0.98159631
1.00000000
## NOx.GT.        0.780462936  0.62254930  0.04885537  0.61614877
0.60617926
## PT08.S3.NOx.  -0.619318315 -0.77054354 -0.19077921 -0.73350297
-0.79579163
## NO2.GT.        0.656001649  0.56344173  0.12100938  0.53331319
0.56193774
## PT08.S4.NO2.   0.548481357  0.68236292  0.25768400  0.76457839
0.77696865
## PT08.S5.O3.    0.763513032  0.89941732  0.22919013  0.86571073
0.88063309
```

```
## T             0.006049053  0.04898505  0.03017121  0.19927329
0.24155572
## RH            0.041137032  0.11440012 -0.04686398 -0.06181193
-0.09045007
## AH            0.022863916  0.13572782 -0.01215017  0.16848094
0.18719567
##                  NOx.GT. PT08.S3.NOx.     NO2.GT. PT08.S4.NO2. PT08.S5.O3.
## CO.GT.         0.78046294  -0.61931831  0.65600165   0.54848136
0.76351303
## PT08.S1.CO.    0.62254930  -0.77054354  0.56344173   0.68236292
0.89941732
## NMHC.GT.       0.04885537  -0.19077921  0.12100938   0.25768400
0.22919013
## C6H6.GT.       0.61614877  -0.73350297  0.53331319   0.76457839
0.86571073
## PT08.S2.NMHC.  0.60617926  -0.79579163  0.56193774   0.77696865
0.88063309
## NOx.GT.        1.00000000  -0.57243986  0.76071574   0.20082479
0.69482257
## PT08.S3.NOx.  -0.57243986   1.00000000 -0.57418076  -0.53841242
-0.79533702
## NO2.GT.        0.76071574  -0.57418076  1.00000000   0.13998573
0.63042540
## PT08.S4.NO2.   0.20082479  -0.53841242  0.13998573   1.00000000
0.59076410
## PT08.S5.O3.    0.69482257  -0.79533702  0.63042540   0.59076410
1.00000000
## T             -0.24570818  -0.14480191 -0.16938010   0.56118317
-0.02681366
## RH             0.18393973  -0.05681926 -0.08213459  -0.03217158
0.12477593
## AH            -0.14828604  -0.23159695 -0.29820576   0.62951123
0.07115105
##                         T          RH          AH
## CO.GT.         0.006049053  0.04113703  0.02286392
## PT08.S1.CO.    0.048985051  0.11440012  0.13572782
## NMHC.GT.       0.030171212 -0.04686398 -0.01215017
## C6H6.GT.       0.199273295 -0.06181193  0.16848094
## PT08.S2.NMHC.  0.241555716 -0.09045007  0.18719567
## NOx.GT.       -0.245708185  0.18393973 -0.14828604
## PT08.S3.NOx.  -0.144801910 -0.05681926 -0.23159695
## NO2.GT.       -0.169380104 -0.08213459 -0.29820576
## PT08.S4.NO2.   0.561183167 -0.03217158  0.62951123
## PT08.S5.O3.   -0.026813661  0.12477593  0.07115105
## T              1.000000000 -0.57862533  0.65645249
## RH            -0.578625331  1.00000000  0.16788952
## AH             0.656452492  0.16788952  1.00000000

# heatmap
ggplot(data = melt(cor_mtx), aes(Var2, Var1, fill = value))+
geom_tile(color = "black")+
theme(axis.text.x = element_text(angle = 90))+
 coord_fixed()
```



4) Linear regression models. Variable C6H6.GT. against all other variables.

```
fit <- lm(data = df_named[,1:13], formula =  C6H6.GT. ~. )

# significant dependencies are marked with *** and **
summary(fit)

##
## Call:
## lm(formula = C6H6.GT. ~ ., data = df_named[, 1:13])
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -7.6701 -0.7221 -0.1927  0.5540 17.1756
##
## Coefficients:
##                 Estimate Std. Error t value Pr(>|t|)
## (Intercept)   -2.041e+01  2.274e-01 -89.755  < 2e-16 ***
## CO.GT.         2.359e-01  2.130e-02  11.078  < 2e-16 ***
## PT08.S1.CO.    1.322e-03  1.611e-04   8.207 2.56e-16 ***
## NMHC.GT.       2.873e-04  2.001e-04   1.436  0.15117
## PT08.S2.NMHC.  2.943e-02  2.015e-04 146.050  < 2e-16 ***
## NOx.GT.        1.712e-03  1.481e-04  11.560  < 2e-16 ***
## PT08.S3.NOx.   4.113e-03  1.030e-04  39.927  < 2e-16 ***
## NO2.GT.       -9.082e-03  5.082e-04 -17.871  < 2e-16 ***
## PT08.S4.NO2.  -3.325e-04  1.281e-04  -2.595  0.00946 ** 
## PT08.S5.O3.   -1.310e-04  8.934e-05  -1.466  0.14264    
## T             -9.504e-02  5.150e-03 -18.454  < 2e-16 ***
## RH            -2.409e-02  1.988e-03 -12.115  < 2e-16 ***
## AH             1.513e+00  9.656e-02  15.673  < 2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 
## Residual standard error: 1.153 on 9344 degrees of freedom
## Multiple R-squared:  0.9752, Adjusted R-squared:  0.9751 
## F-statistic: 3.059e+04 on 12 and 9344 DF,  p-value: < 2.2e-16
```

5) Explore dependencies more carefully

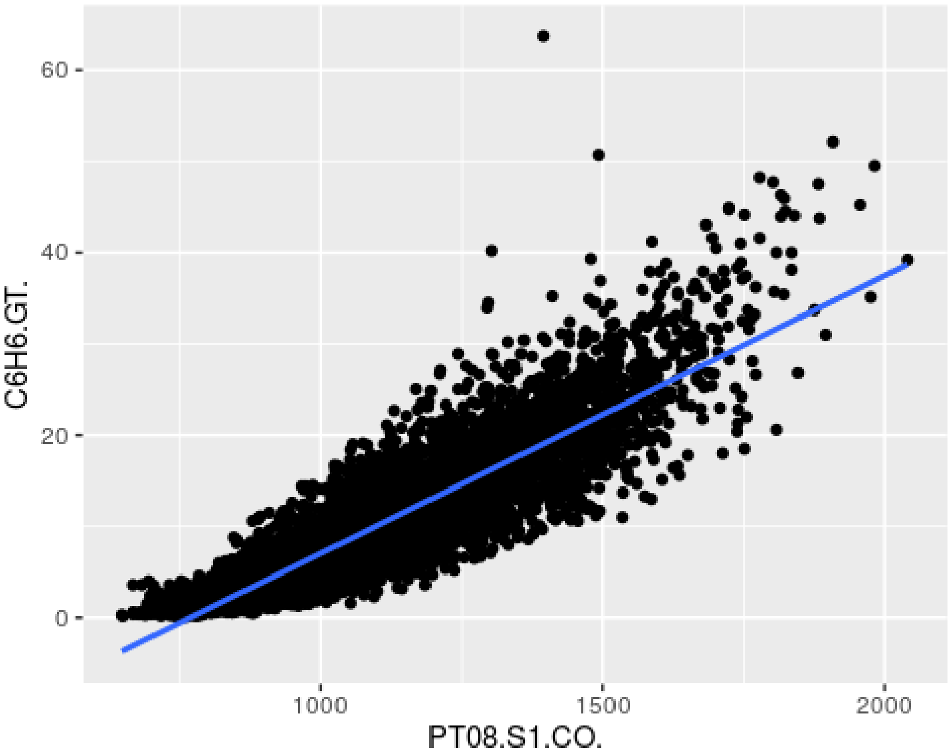
We split data to train and test dataset

```
sample <- sample.int(n = nrow(df_named), size = floor(.75*
nrow(df_named)))

train <- df_named[sample,]
nrow(train)

## [1] 7017

test <- df_named[-sample,]
nrow(test)

## [1] 2340
```

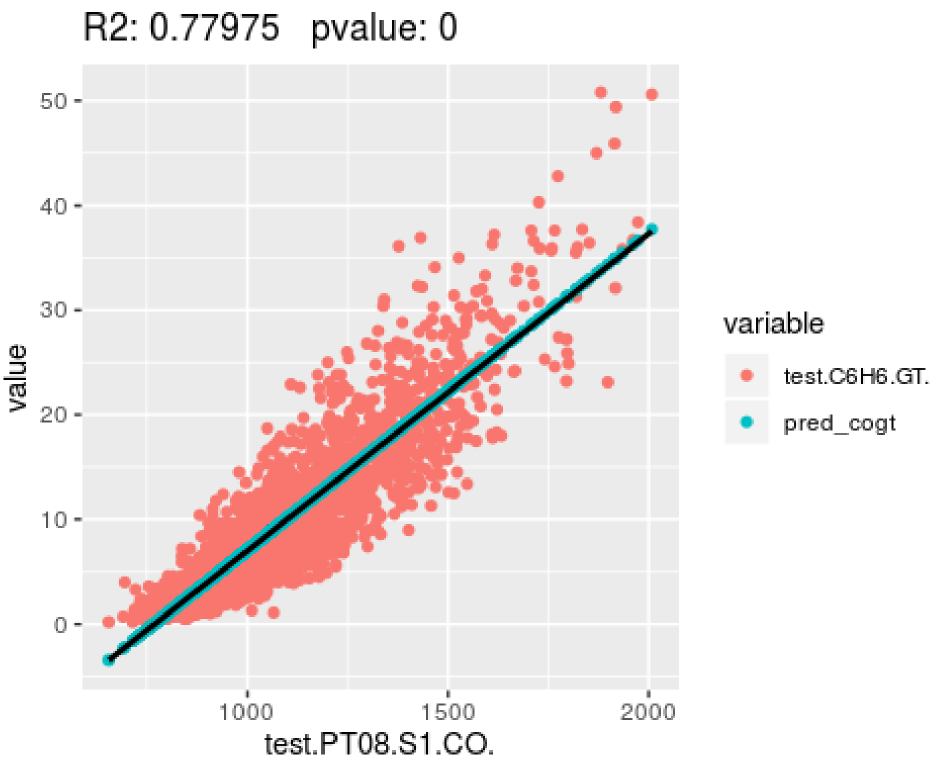
Check C6H6.GT. against PT08.S1.CO.

```
# model
fit_cogt <- lm(data = train[,1:13], formula =  C6H6.GT. ~ PT08.S1.CO. )
cogt <- summary(fit_cogt)
cogt

## 
## Call:
## lm(formula = C6H6.GT. ~ PT08.S1.CO., data = train[, 1:13])
## 
## Residuals:
##     Min      1Q  Median      3Q     Max 
## -12.300  -1.920  -0.230   1.807  44.659 
## 
## Coefficients:
##               Estimate Std. Error t value Pr(>|t|)    
## (Intercept) -23.356848   0.215721  -108.3   <2e-16 ***
## PT08.S1.CO.   0.030415   0.000193   157.6   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
## 
```

```
## Residual standard error: 3.425 on 7015 degrees of freedom
## Multiple R-squared:  0.7798, Adjusted R-squared:  0.7797
## F-statistic: 2.484e+04 on 1 and 7015 DF,  p-value: < 2.2e-16

# plot
ggplot(train[,1:13], aes( PT08.S1.CO., C6H6.GT.))+
  geom_point()+
  geom_smooth(method='lm')
```



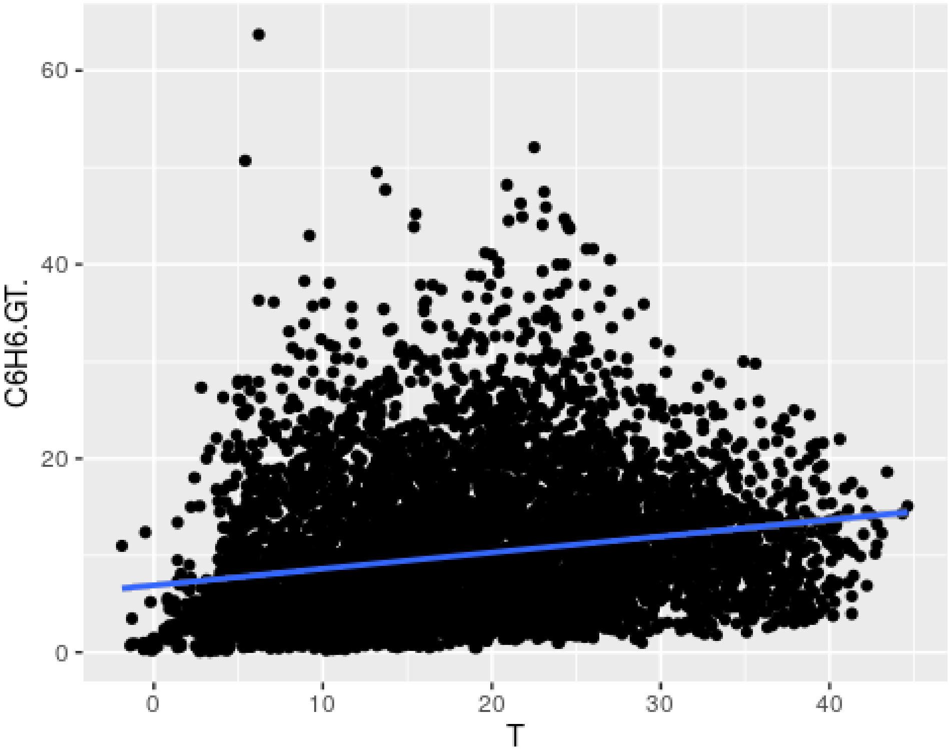
```
# predict test values
pred_cogt <- predict(fit_cogt, test)

# plot actual and predicted values
test_plot <- data.frame(test$PT08.S1.CO., test$C6H6.GT., pred_cogt)

qplot(test.PT08.S1.CO., value,
      data = melt(test_plot, measure.vars=c("test.C6H6.GT.", "pred_cogt")),
      colour=variable) +
  geom_smooth(method='lm', col='black')+
  ggtitle(paste("R2:", round(cogt$adj.r.squared, 5), "  pvalue:",
round(cogt$coefficients[, 4], 5) ))
```



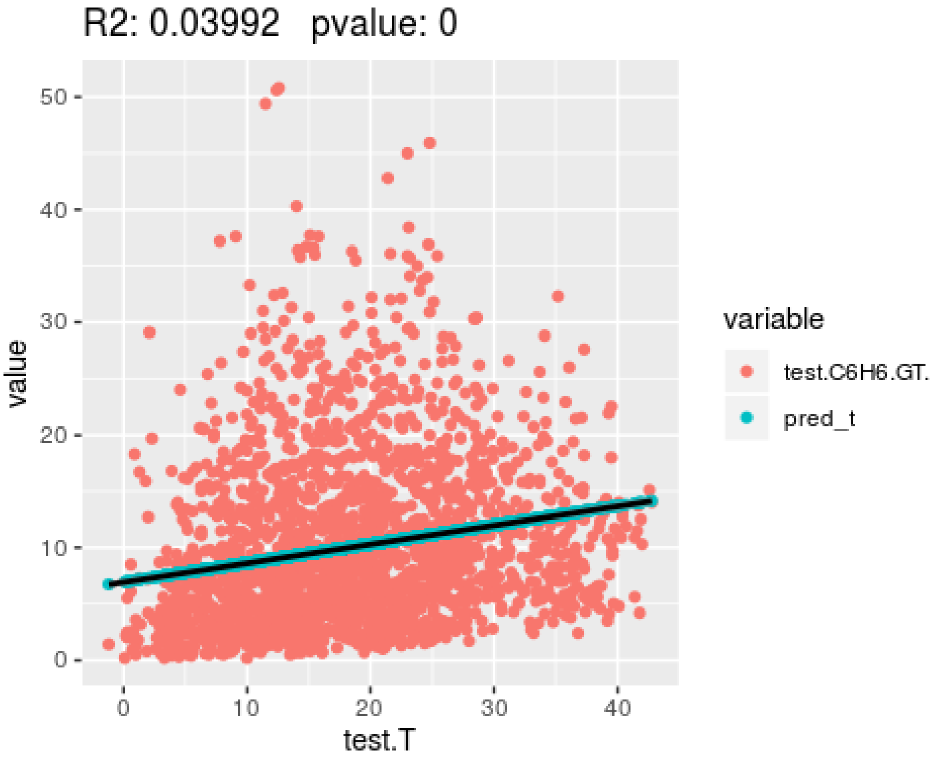
Another model: C6H6.GT. against T We can see, that linear regression probably found the nonexistent dependency due to nonlinear data

```
# model
fit_t <- lm(data = train[,1:13], formula =  C6H6.GT. ~ T )
t <- summary(fit_t)
t

##
## Call:
## lm(formula = C6H6.GT. ~ T, data = train[, 1:13])
##
## Residuals:
##     Min      1Q  Median      3Q     Max
## -10.805  -5.152  -1.737   3.212  55.715
##
## Coefficients:
##             Estimate Std. Error t value Pr(>|t|)
## (Intercept) 6.941661   0.199431   34.81   <2e-16 ***
## T           0.168298   0.009837   17.11   <2e-16 ***
## ---
## Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
##
## Residual standard error: 7.152 on 7015 degrees of freedom
## Multiple R-squared:  0.04006,    Adjusted R-squared:  0.03992
## F-statistic: 292.7 on 1 and 7015 DF,  p-value: < 2.2e-16
```

```
ggplot(train[,1:13], aes( T, C6H6.GT.))+
  geom_point()+
  geom_smooth(method='lm')
```



```
# predict test values based on the model
pred_t <- predict(fit_t, test)

t_plot <- data.frame(test$T, test$C6H6.GT., pred_t)

# plot actual and predicted values
qplot(test.T, value,
      data = melt(t_plot, measure.vars=c("test.C6H6.GT.", "pred_t")),
      colour=variable) +
  geom_smooth(method='lm', col='black')+
   ggtitle(paste("R2:", round(t$adj.r.squared, 5), "  pvalue:",
round(t$coefficients[, 4], 5) ))
```


R2: 0.03992   pvalue: 0
value
50
40
30
20
10
0
0
10
20
30
40
test.T
variable
● test.C6H6.GT.
● pred_t