# **Prediction Assignment Writeup**

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# **Executive summary**

First, it is made an exploratory data analysis to get to know better the data we're dealing with. With regard to the cross validation, the provided training dataset, after having been properly treated (cleaned), was under subsampling, randomly and without replacement. The result was two subsamples, training\_training (75% of the original data) and training\_testing (25% of it). Thus, the two models were fitted within the training\_training and tested under training\_testing. As for the expected out-of-sample error, it is the error rate one gets on a new data set, also called generalization error. In mathematical terms, it is given by 1 - accuracy in the cross validation dataset. The expected out-of-sample error was about 0.5% for the Random Forest model. Afterwards, it is tested two models for prediction, Decision Tree and Random Forest. We found that Random Forest model provided the biggest accuracy, which is why was the chosen for the final model.

## Description of the data

The data was extracted from a research on the measurement of not only how much people do activities but also how well they do it. In order to collect these data (i.e. Weight Lifting Exercises Dataset) the researchers made an experiment in which they asked six male participants aged between 20-28 years old to perform one set of 10 repetitions of the Unilateral Dumbbell Biceps Curl in 5 different fashions: exactly according to the specification (Class A), throwing the elbows to the front (Class B), lifting the dumbbell only halfway (Class C), lowering the dumbbell only halfway (Class D) and throwing the hips to the front (Class E). In short, Class A corresponds to the specified execution of the exercise, whereas the other remaining four to the common mistakes (thus proxies to measure the quality of the exercise).

The aim of this project is to predict the manner in which a set of six male participants did the required exercise. This is the "classe" variable in the training set. You may use any of the other variables to predict with. You should create a report describing how you built your model, how you used cross validation, what you think the expected out of sample error is, and why you made the choices you did. You will also use your prediction model to predict 20 different test cases.

# Loading packages and the dataset

```
set.seed(1234)
library(randomForest); library(caret); library(rpart); library(ggplot2); library(lattice); li
brary(rpart.plot); library(rattle)
```

```
## Warning: package 'randomForest' was built under R version 3.5.3
```

```
## randomForest 4.6-14
```

## Type rfNews() to see new features/changes/bug fixes.

```
## Warning: package 'caret' was built under R version 3.5.3
## Loading required package: lattice
## Warning: package 'lattice' was built under R version 3.5.3
## Loading required package: ggplot2
## Attaching package: 'ggplot2'
## The following object is masked from 'package:randomForest':
##
##
       margin
## Warning: package 'rpart' was built under R version 3.5.3
## Loading required package: tibble
## Warning: package 'tibble' was built under R version 3.5.3
## Loading required package: bitops
## Warning: package 'bitops' was built under R version 3.5.2
## Rattle: A free graphical interface for data science with R.
## Version 5.4.0 Copyright (c) 2006-2020 Togaware Pty Ltd.
## Type 'rattle()' to shake, rattle, and roll your data.
##
## Attaching package: 'rattle'
## The following object is masked from 'package:randomForest':
##
##
       importance
training <- read.csv("pml-training.csv", na.strings = c("NA", "#DIV/0!", ""))</pre>
testing <- read.csv("pml-testing.csv", na.strings = c("NA", "#DIV/0!", ""))</pre>
```

# Exploratory data analysis

As there is a lot of information provided by the data set, the exploratory analysis is only made for the training data for an example.

```
dim(training); summary(training); str(training)
```

## [1] 19622 160

```
##
          Χ
                       user_name
                                    raw timestamp part 1 raw timestamp part 2
##
   Min.
          :
                    adelmo :3892
                                    Min.
                                            :1.322e+09
                                                          Min.
                                                                 :
                                                                     294
                1
    1st Qu.: 4906
##
                    carlitos:3112
                                    1st Qu.:1.323e+09
                                                          1st Qu.:252912
    Median: 9812
                    charles :3536
                                    Median :1.323e+09
                                                          Median :496380
##
##
    Mean
           : 9812
                    eurico :3070
                                    Mean
                                            :1.323e+09
                                                          Mean
                                                               :500656
##
    3rd Qu.:14717
                    jeremy :3402
                                    3rd Qu.:1.323e+09
                                                          3rd Qu.:751891
   Max.
         :19622
                    pedro
                            :2610
                                           :1.323e+09
                                                          Max.
                                                                 :998801
##
                                    Max.
##
                                                            roll belt
##
             cvtd timestamp new window
                                           num window
   28/11/2011 14:14: 1498
                             no:19216
                                         Min.
                                                 : 1.0
                                                          Min.
                                                                 :-28.90
##
                             yes: 406
##
   05/12/2011 11:24: 1497
                                         1st Qu.:222.0
                                                          1st Qu.: 1.10
    30/11/2011 17:11: 1440
                                         Median :424.0
                                                          Median :113.00
##
##
   05/12/2011 11:25: 1425
                                         Mean
                                               :430.6
                                                          Mean : 64.41
##
    02/12/2011 14:57: 1380
                                         3rd Qu.:644.0
                                                          3rd Qu.:123.00
   02/12/2011 13:34: 1375
                                         Max.
                                                 :864.0
                                                          Max.
                                                                 :162.00
    (Other)
##
                    :11007
      pitch belt
##
                                         total accel belt kurtosis roll belt
                          yaw_belt
           :-55.8000
##
   Min.
                       Min.
                             :-180.00
                                         Min.
                                                 : 0.00
                                                           Min.
                                                                  :-2.121
##
    1st Qu.: 1.7600
                       1st Qu.: -88.30
                                         1st Qu.: 3.00
                                                           1st Qu.:-1.329
   Median : 5.2800
                       Median : -13.00
                                         Median :17.00
                                                           Median :-0.899
##
##
   Mean
           : 0.3053
                       Mean
                             : -11.21
                                         Mean
                                                 :11.31
                                                           Mean
                                                                 :-0.220
    3rd Qu.: 14.9000
                       3rd Qu.: 12.90
                                         3rd Qu.:18.00
                                                           3rd Qu.:-0.219
##
   Max.
           : 60.3000
                       Max.
                              : 179.00
                                         Max.
                                                 :29.00
                                                           Max.
                                                                  :33.000
##
##
                                                           NA's
                                                                  :19226
   kurtosis_picth_belt kurtosis_yaw_belt skewness_roll_belt skewness_roll_belt.1
##
##
   Min.
           :-2.190
                        Mode:logical
                                          Min.
                                                  :-5.745
                                                              Min.
                                                                     :-7.616
                        NA's:19622
   1st Qu.:-1.107
                                          1st Qu.:-0.444
                                                              1st Qu.:-1.114
##
##
   Median :-0.151
                                          Median : 0.000
                                                              Median :-0.068
##
   Mean
           : 4.334
                                          Mean
                                                 :-0.026
                                                              Mean
                                                                     :-0.296
    3rd Ou.: 3.178
##
                                          3rd Qu.: 0.417
                                                              3rd Qu.: 0.661
##
   Max.
           :58.000
                                          Max.
                                                  : 3.595
                                                              Max.
                                                                     : 7.348
   NA's
           :19248
                                          NA's
                                                  :19225
                                                              NA's
                                                                     :19248
##
    skewness_yaw_belt max_roll_belt
                                        max_picth_belt
                                                          max_yaw_belt
##
                      Min.
   Mode:logical
                             :-94.300
                                               : 3.00
                                                         Min.
##
                                        Min.
                                                                :-2.10
   NA's:19622
##
                      1st Qu.:-88.000
                                        1st Qu.: 5.00
                                                         1st Qu.:-1.30
##
                      Median : -5.100
                                        Median :18.00
                                                         Median :-0.90
##
                      Mean
                             : -6.667
                                        Mean
                                               :12.92
                                                         Mean
                                                                :-0.22
##
                      3rd Ou.: 18.500
                                        3rd Qu.:19.00
                                                         3rd Ou.:-0.20
##
                      Max.
                             :180.000
                                        Max.
                                                :30.00
                                                         Max.
                                                                :33.00
                                                :19216
##
                      NA's
                                        NA's
                                                         NA's
                             :19216
                                                                :19226
##
    min_roll_belt
                      min_pitch_belt
                                       min_yaw_belt
                                                       amplitude roll belt
##
    Min.
          :-180.00
                      Min.
                             : 0.00
                                             :-2.10
                                                       Min.
                                                              : 0.000
                                      Min.
    1st Qu.: -88.40
                                                       1st Qu.:
##
                      1st Qu.: 3.00
                                      1st Qu.:-1.30
                                                                 0.300
   Median : -7.85
                                                       Median :
##
                      Median :16.00
                                      Median :-0.90
                                                                1.000
##
   Mean
           : -10.44
                      Mean
                             :10.76
                                      Mean :-0.22
                                                       Mean
                                                              : 3.769
##
    3rd Qu.:
               9.05
                      3rd Qu.:17.00
                                      3rd Qu.:-0.20
                                                       3rd Qu.: 2.083
    Max.
           : 173.00
                                                              :360.000
##
                      Max.
                             :23.00
                                      Max.
                                              :33.00
                                                       Max.
    NA's
                                      NA's
##
           :19216
                      NA's
                             :19216
                                              :19226
                                                       NA's
                                                              :19216
##
    amplitude_pitch_belt amplitude_yaw_belt var_total_accel_belt avg_roll_belt
   Min.
           : 0.000
                         Min.
                                :0
                                            Min.
                                                    : 0.000
                                                                  Min.
                                                                         :-27.40
##
##
    1st Qu.: 1.000
                         1st Qu.:0
                                             1st Qu.: 0.100
                                                                  1st Qu.: 1.10
   Median : 1.000
                         Median :0
##
                                             Median : 0.200
                                                                  Median :116.35
##
    Mean
           : 2.167
                         Mean
                                :0
                                             Mean
                                                    : 0.926
                                                                  Mean
                                                                         : 68.06
##
    3rd Qu.: 2.000
                         3rd Qu.:0
                                             3rd Qu.: 0.300
                                                                  3rd Qu.:123.38
##
   Max.
           :12.000
                                                    :16.500
                                                                         :157.40
                         Max.
                                :0
                                             Max.
                                                                  Max.
                                                                         :19216
                                :19226
##
    NA's
           :19216
                         NA's
                                             NA's
                                                    :19216
                                                                  NA's
    stddev_roll_belt var_roll_belt
                                       avg_pitch_belt
                                                          stddev_pitch_belt
```

```
##
   Min.
          : 0.000
                    Min.
                           : 0.000
                                      Min.
                                             :-51.400
                                                        Min.
                                                               :0.000
##
   1st Qu.: 0.200
                    1st Qu.:
                              0.000
                                      1st Qu.: 2.025
                                                        1st Qu.:0.200
##
   Median : 0.400
                    Median : 0.100
                                      Median : 5.200
                                                        Median :0.400
##
   Mean : 1.337
                    Mean
                          : 7.699
                                      Mean
                                            : 0.520
                                                        Mean
                                                               :0.603
    3rd Qu.: 0.700
                    3rd Qu.: 0.500
                                      3rd Qu.: 15.775
                                                        3rd Qu.:0.700
##
##
   Max.
         :14.200
                    Max.
                          :200.700
                                      Max.
                                           : 59.700
                                                        Max.
                                                              :4.000
   NA's
          :19216
                    NA's
                                      NA's
                                             :19216
                                                        NA's
                           :19216
                                                               :19216
##
   var_pitch_belt
##
                     avg_yaw_belt
                                       stddev_yaw_belt
                                                          var_yaw_belt
   Min.
         : 0.000
                    Min. :-138.300
                                       Min.
                                             : 0.000
                                                       Min. :
##
                                                                     0.000
##
    1st Qu.: 0.000
                    1st Qu.: -88.175
                                       1st Qu.: 0.100
                                                         1st Qu.:
                                                                     0.010
##
   Median : 0.100
                    Median : -6.550
                                       Median : 0.300
                                                         Median :
                                                                     0.090
                          : -8.831
   Mean : 0.766
                    Mean
                                       Mean : 1.341
                                                         Mean
                                                              : 107.487
##
##
    3rd Qu.: 0.500
                    3rd Qu.: 14.125
                                       3rd Qu.: 0.700
                                                         3rd Qu.:
                                                                     0.475
                                       Max.
   Max.
         :16.200
                           : 173.500
                                             :176.600
                                                               :31183.240
##
                    Max.
                                                         Max.
##
   NA's
          :19216
                    NA's
                           :19216
                                       NA's
                                              :19216
                                                         NA's
                                                                :19216
                        gyros_belt y
                                           gyros_belt z
##
    gyros belt x
                                                             accel belt x
                                                 :-1.4600
                                                                   :-120.000
##
   Min.
          :-1.040000
                       Min.
                              :-0.64000
                                          Min.
                                                            Min.
                                                            1st Qu.: -21.000
##
   1st Qu.:-0.030000
                       1st Qu.: 0.00000
                                          1st Qu.:-0.2000
   Median : 0.030000
                       Median : 0.02000
                                         Median :-0.1000
                                                          Median : -15.000
##
##
   Mean
          :-0.005592
                       Mean
                             : 0.03959
                                          Mean :-0.1305
                                                           Mean
                                                                  : -5.595
    3rd Qu.: 0.110000
                       3rd Qu.: 0.11000
                                          3rd Qu.:-0.0200
                                                            3rd Qu.: -5.000
##
   Max.
                                                 : 1.6200
          : 2.220000
                              : 0.64000
                                                                  : 85.000
##
                       Max.
                                          Max.
                                                            Max.
##
    accel_belt_y
##
                     accel_belt_z
                                      magnet_belt_x
                                                      magnet_belt_y
##
   Min.
          :-69.00
                    Min.
                          :-275.00
                                      Min.
                                            :-52.0
                                                      Min.
                                                             :354.0
    1st Qu.: 3.00
                    1st Qu.:-162.00
                                      1st Qu.: 9.0
                                                      1st Qu.:581.0
##
##
   Median : 35.00
                    Median :-152.00
                                      Median : 35.0
                                                      Median :601.0
   Mean : 30.15
                    Mean : -72.59
                                      Mean : 55.6
##
                                                      Mean
                                                            :593.7
                    3rd Qu.: 27.00
    3rd Qu.: 61.00
                                      3rd Qu.: 59.0
                                                      3rd Qu.:610.0
##
##
   Max. :164.00
                    Max. : 105.00
                                      Max. :485.0
                                                      Max. :673.0
##
##
   magnet_belt_z
                       roll_arm
                                        pitch_arm
                                                           yaw_arm
##
   Min.
         :-623.0
                    Min.
                          :-180.00
                                      Min.
                                             :-88.800
                                                        Min.
                                                             :-180.0000
                    1st Qu.: -31.77
                                      1st Qu.:-25.900
   1st Qu.:-375.0
                                                        1st Qu.: -43.1000
##
##
   Median :-320.0
                    Median :
                               0.00
                                      Median : 0.000
                                                        Median :
                                                                   0.0000
   Mean :-345.5
                                                        Mean : -0.6188
##
                    Mean : 17.83
                                      Mean : -4.612
                                                        3rd Qu.: 45.8750
##
    3rd Qu.:-306.0
                    3rd Qu.: 77.30
                                      3rd Qu.: 11.200
##
   Max. : 293.0
                    Max.
                          : 180.00
                                      Max. : 88.500
                                                        Max.
                                                             : 180.0000
##
##
   total_accel_arm var_accel_arm
                                     avg_roll_arm
                                                      stddev_roll_arm
                         : 0.00
                                           :-166.67
##
   Min.
          : 1.00
                   Min.
                                    Min.
                                                           : 0.000
                                                      Min.
                                    1st Qu.: -38.37
##
   1st Ou.:17.00
                   1st Qu.: 9.03
                                                      1st Qu.: 1.376
   Median :27.00
                   Median : 40.61
                                    Median :
                                               0.00
                                                      Median : 5.702
##
##
   Mean
         :25.51
                   Mean
                         : 53.23
                                    Mean
                                           : 12.68
                                                      Mean
                                                            : 11.201
    3rd Qu.:33.00
                   3rd Qu.: 75.62
                                    3rd Qu.: 76.33
                                                      3rd Qu.: 14.921
##
                   Max.
                          :331.70
                                    Max.
                                           : 163.33
##
   Max.
         :66.00
                                                      Max.
                                                             :161.964
                          :19216
                                    NA's
                                           :19216
                                                      NA's
##
                   NA's
                                                             :19216
##
    var roll arm
                       avg pitch arm
                                         stddev_pitch_arm var_pitch_arm
                                              : 0.000
##
   Min.
         :
               0.000
                       Min.
                              :-81.773
                                         Min.
                                                          Min.
                                                                :
                                                                     0.000
    1st Qu.:
               1.898
                       1st Qu.:-22.770
                                         1st Qu.: 1.642
                                                          1st Qu.:
##
                                                                     2.697
                                                          Median : 66.146
                       Median : 0.000
##
   Median :
              32.517
                                         Median : 8.133
##
   Mean
          : 417.264
                       Mean
                             : -4.901
                                         Mean
                                                :10.383
                                                          Mean
                                                                 : 195.864
##
    3rd Qu.: 222.647
                       3rd Qu.: 8.277
                                         3rd Qu.:16.327
                                                          3rd Qu.: 266.576
##
   Max.
          :26232.208
                       Max.
                              : 75.659
                                         Max.
                                                :43.412
                                                          Max.
                                                                 :1884.565
   NA's
                                         NA's
                                                          NA's
##
          :19216
                       NA's
                              :19216
                                                :19216
                                                                 :19216
##
    avg_yaw_arm
                      stddev_yaw_arm
                                         var_yaw_arm
                                                             gyros_arm_x
##
   Min.
           :-173.440
                      Min.
                             : 0.000
                                        Min.
                                                    0.000
                                                            Min.
                                                                   :-6.37000
                                              :
    1st Ou.: -29.198
                      1st Qu.: 2.577
                                        1st Qu.:
                                                    6.642
                                                            1st Qu.:-1.33000
```

```
##
   Median :
              0.000
                      Median : 16.682
                                       Median : 278.309
                                                          Median : 0.08000
##
         :
              2.359
                      Mean
                           : 22.270
                                             : 1055.933
                                                                : 0.04277
   Mean
                                       Mean
                                                          Mean
##
   3rd Ou.: 38.185
                      3rd Ou.: 35.984
                                       3rd Ou.: 1294.850
                                                          3rd Ou.: 1.57000
##
   Max.
         : 152.000
                      Max.
                            :177.044
                                       Max.
                                            :31344.568
                                                          Max.
                                                                 : 4.87000
   NA's
          :19216
                      NA's
                            :19216
                                       NA's
                                              :19216
##
##
    gyros_arm_y
                      gyros_arm_z
                                       accel_arm_x
                                                        accel_arm_y
                                                             :-318.0
   Min.
          :-3.4400
                     Min.
                          :-2.3300
                                      Min.
                                             :-404.00
                                                       Min.
##
##
   1st Qu.:-0.8000
                     1st Qu.:-0.0700
                                      1st Qu.:-242.00
                                                       1st Qu.: -54.0
##
   Median :-0.2400
                     Median : 0.2300
                                      Median : -44.00
                                                       Median: 14.0
##
   Mean
          :-0.2571
                    Mean
                           : 0.2695
                                      Mean : -60.24
                                                       Mean
                                                             : 32.6
##
   3rd Qu.: 0.1400
                     3rd Qu.: 0.7200
                                      3rd Qu.: 84.00
                                                       3rd Qu.: 139.0
##
   Max.
          : 2.8400
                           : 3.0200
                                             : 437.00
                     Max.
                                      Max.
                                                       Max.
                                                              : 308.0
##
                                      magnet_arm_y
##
    accel_arm_z
                     magnet_arm_x
                                                      magnet_arm_z
##
   Min.
          :-636.00
                     Min.
                           :-584.0
                                     Min.
                                           :-392.0
                                                     Min.
                                                            :-597.0
##
   1st Qu.:-143.00
                     1st Qu.:-300.0
                                     1st Qu.: -9.0
                                                      1st Qu.: 131.2
   Median : -47.00
                    Median : 289.0
                                                     Median : 444.0
                                     Median : 202.0
##
##
   Mean : -71.25
                     Mean : 191.7
                                     Mean : 156.6
                                                     Mean : 306.5
   3rd Qu.: 23.00
                     3rd Qu.: 637.0
                                     3rd Qu.: 323.0
                                                      3rd Qu.: 545.0
##
##
   Max. : 292.00
                     Max. : 782.0
                                     Max. : 583.0
                                                     Max.
                                                            : 694.0
##
   kurtosis_roll_arm kurtosis_picth_arm kurtosis_yaw_arm skewness_roll_arm
##
          :-1.809
                     Min.
                           :-2.084
                                       Min.
                                             :-2.103
                                                       Min.
                                                              :-2.541
##
   Min.
   1st Qu.:-1.345
                     1st Qu.:-1.280
                                       1st Qu.:-1.220
##
                                                       1st Qu.:-0.561
##
   Median :-0.894
                    Median :-1.010
                                       Median :-0.733
                                                       Median : 0.040
   Mean :-0.366
                    Mean :-0.542
                                       Mean : 0.406
                                                       Mean : 0.068
##
   3rd Qu.:-0.038
                     3rd Qu.:-0.379
##
                                       3rd Qu.: 0.115
                                                       3rd Qu.: 0.671
##
   Max. :21.456
                    Max. :19.751
                                       Max. :56.000
                                                       Max. : 4.394
   NA's
          :19294
                     NA's
                           :19296
                                       NA's
                                                       NA's
##
                                              :19227
                                                              :19293
##
   skewness_pitch_arm skewness_yaw_arm max_roll_arm
                                                       max_picth_arm
         :-4.565
                    Min. :-6.708 Min.
                                            :-73.100
                                                             :-173.000
##
                                                       Min.
   1st Qu.:-0.618
                                                       1st Qu.: -1.975
##
                      1st Qu.:-0.743
                                      1st Qu.: -0.175
##
   Median :-0.035
                      Median :-0.133 Median : 4.950
                                                       Median : 23.250
   Mean :-0.065
                     Mean :-0.229 Mean : 11.236 Mean : 35.751
##
##
   3rd Qu.: 0.454
                      3rd Qu.: 0.344
                                      3rd Qu.: 26.775
                                                       3rd Qu.: 95.975
                     Max. : 7.483
                                            : 85.500
##
   Max.
         : 3.043
                                      Max.
                                                       Max.
                                                             : 180.000
   NA's
                      NA's
                                      NA's
                                                       NA's
##
          :19296
                            :19227
                                             :19216
                                                              :19216
##
    max yaw arm
                    min roll arm
                                   min pitch arm
                                                     min yaw arm
                                          :-180.00 Min. : 1.00
   Min. : 4.00
                   Min. :-89.10
##
                                   Min.
##
   1st Qu.:29.00
                   1st Qu.:-41.98
                                  1st Qu.: -72.62
                                                    1st Qu.: 8.00
##
   Median :34.00
                   Median :-22.45
                                  Median : -33.85
                                                    Median :13.00
   Mean :35.46
                         :-21.22
##
                   Mean
                                   Mean
                                        : -33.92
                                                    Mean
                                                           :14.66
##
   3rd Qu.:41.00
                   3rd Qu.: 0.00
                                   3rd Qu.:
                                              0.00
                                                     3rd Qu.:19.00
   Max.
                         : 66.40
                                          : 152.00
##
          :65.00
                   Max.
                                   Max.
                                                    Max.
                                                           :38.00
##
   NA's
          :19216
                   NA's
                          :19216
                                   NA's
                                          :19216
                                                     NA's
                                                           :19216
   amplitude_roll_arm amplitude_pitch_arm amplitude_yaw_arm roll_dumbbell
##
##
   Min.
          : 0.000
                      Min.
                             : 0.000
                                         Min.
                                                : 0.00
                                                          Min.
                                                                 :-153.71
##
   1st Qu.: 5.425
                      1st Qu.: 9.925
                                         1st Qu.:13.00
                                                          1st Qu.: -18.49
   Median : 28.450
                      Median : 54.900
                                                          Median : 48.17
##
                                         Median :22.00
##
   Mean
         : 32.452
                      Mean : 69.677
                                         Mean :20.79
                                                          Mean : 23.84
   3rd Qu.: 50.960
                      3rd Qu.:115.175
                                                          3rd Qu.: 67.61
##
                                         3rd Qu.:28.75
##
   Max.
          :119.500
                      Max.
                             :360.000
                                         Max.
                                                :52.00
                                                          Max.
                                                                : 153.55
##
   NA's
          :19216
                      NA's
                            :19216
                                         NA's
                                                :19216
##
   pitch dumbbell
                     yaw dumbbell
                                       kurtosis roll dumbbell
##
   Min.
          :-149.59
                     Min.
                           :-150.871
                                       Min. :-2.174
                     1st Qu.: -77.644
   1st Qu.: -40.89
##
                                       1st Qu.:-0.682
##
   Median : -20.96
                     Median : -3.324
                                       Median :-0.033
   Mean
          : -10.78
                     Mean
                           :
                               1.674
                                       Mean
                                              : 0.452
```

```
##
   3rd Qu.: 17.50
                      3rd Qu.: 79.643
                                         3rd Qu.: 0.940
##
   Max.
           : 149.40
                             : 154.952
                                         Max.
                                                :54.998
                      Max.
##
                                         NA's
                                                :19221
   kurtosis_picth_dumbbell kurtosis_yaw_dumbbell skewness_roll_dumbbell
##
           :-2.200
                            Mode:logical
                                                  Min.
                                                          :-7.384
##
   1st Qu.:-0.721
                            NA's:19622
##
                                                  1st Qu.:-0.581
   Median :-0.133
                                                  Median :-0.076
##
   Mean
         : 0.286
##
                                                  Mean
                                                         :-0.115
##
   3rd Qu.: 0.584
                                                  3rd Qu.: 0.400
##
   Max.
           :55.628
                                                  Max.
                                                          : 1.958
   NA's
                                                  NA's
##
           :19218
                                                          :19220
    skewness_pitch_dumbbell skewness_yaw_dumbbell max_roll_dumbbell
##
##
   Min.
           :-7.447
                            Mode:logical
                                                  Min.
                                                          :-70.10
##
   1st Qu.:-0.526
                            NA's:19622
                                                  1st Qu.:-27.15
##
   Median :-0.091
                                                  Median : 14.85
##
   Mean
         :-0.035
                                                  Mean
                                                         : 13.76
   3rd Qu.: 0.505
                                                  3rd Qu.: 50.58
##
##
   Max.
         : 3.769
                                                  Max.
                                                          :137.00
##
   NA's
           :19217
                                                  NA's
                                                          :19216
##
   max picth dumbbell max yaw dumbbell min roll dumbbell min pitch dumbbell
##
           :-112.90
                       Min. :-2.20
                                        Min. :-149.60
                                                          Min.
                                                                 :-147.00
   1st Qu.: -66.70
                       1st Qu.:-0.70
                                        1st Qu.: -59.67
                                                          1st Qu.: -91.80
##
   Median : 40.05
                       Median : 0.00
                                        Median : -43.55
                                                          Median : -66.15
##
   Mean : 32.75
                       Mean : 0.45
                                        Mean : -41.24 Mean : -33.18
##
##
   3rd Qu.: 133.22
                       3rd Qu.: 0.90
                                        3rd Qu.: -25.20
                                                          3rd Qu.: 21.20
   Max.
         : 155.00
                       Max.
                              :55.00
                                        Max.
                                               : 73.20
                                                          Max.
                                                                 : 120.90
##
                                        NA's
##
   NA's
           :19216
                       NA's
                              :19221
                                               :19216
                                                           NA's
                                                                  :19216
   min yaw dumbbell amplitude roll dumbbell amplitude pitch dumbbell
##
                     Min. : 0.00
                                             Min.
                                                    : 0.00
##
   Min. :-2.20
##
   1st Qu.:-0.70
                     1st Qu.: 14.97
                                             1st Qu.: 17.06
   Median : 0.00
                     Median : 35.05
                                             Median : 41.73
##
           : 0.45
##
   Mean
                     Mean
                           : 55.00
                                             Mean
                                                   : 65.93
##
   3rd Qu.: 0.90
                     3rd Qu.: 81.04
                                             3rd Qu.: 99.55
   Max.
          :55.00
                            :256.48
##
                     Max.
                                             Max.
                                                    :273.59
##
   NA's
           :19221
                     NA's
                            :19216
                                             NA's
                                                    :19216
   amplitude_yaw_dumbbell total_accel_dumbbell var_accel_dumbbell
##
##
   Min.
           :0
                           Min.
                                  : 0.00
                                                Min.
                                                       : 0.000
##
   1st Ou.:0
                           1st Qu.: 4.00
                                                1st Qu.: 0.378
   Median :0
                           Median :10.00
                                                Median : 1.000
##
##
   Mean
                           Mean
                                  :13.72
                                                Mean
                                                       : 4.388
           :0
##
   3rd Ou.:0
                           3rd Ou.:19.00
                                                3rd Ou.: 3.434
   Max.
                                  :58.00
                                                        :230.428
##
           :0
                           Max.
                                                Max.
##
   NA's
           :19221
                                                NA's
                                                        :19216
   avg_roll_dumbbell stddev_roll_dumbbell var_roll_dumbbell avg_pitch_dumbbell
##
##
   Min.
           :-128.96
                      Min.
                             : 0.000
                                           Min.
                                                       0.00
                                                              Min.
                                                                      :-70.73
##
   1st Qu.: -12.33
                      1st Ou.: 4.639
                                           1st Ou.:
                                                      21.52
                                                              1st Ou.:-42.00
   Median : 48.23
                      Median : 12.204
                                                              Median :-19.91
##
                                           Median : 148.95
##
   Mean
           : 23.86
                      Mean
                             : 20.761
                                           Mean
                                                  : 1020.27
                                                              Mean
                                                                     :-12.33
   3rd Qu.: 64.37
                      3rd Qu.: 26.356
##
                                           3rd Qu.: 694.65
                                                              3rd Qu.: 13.21
##
   Max.
           : 125.99
                             :123.778
                                                                      : 94.28
                      Max.
                                           Max.
                                                  :15321.01
                                                              Max.
   NA's
           :19216
                      NA's
                             :19216
                                           NA's
                                                  :19216
                                                              NA's
##
                                                                      :19216
##
    stddev_pitch_dumbbell var_pitch_dumbbell avg_yaw_dumbbell
##
   Min.
           : 0.000
                          Min.
                                 :
                                     0.00
                                             Min.
                                                    :-117.950
   1st Ou.: 3.482
                                             1st Ou.: -76.696
##
                          1st Qu.: 12.12
   Median : 8.089
                                             Median : -4.505
##
                          Median : 65.44
##
   Mean
         :13.147
                          Mean
                                 : 350.31
                                             Mean
                                                   :
                                                        0.202
##
   3rd Qu.:19.238
                          3rd Qu.: 370.11
                                             3rd Qu.:
                                                      71.234
   Max.
           :82.680
                          Max.
                                 :6836.02
                                             Max.
                                                    : 134.905
```

```
NA's
##
           :19216
                          NA's
                                 :19216
                                             NA's
                                                    :19216
##
   stddev_yaw_dumbbell var_yaw_dumbbell
                                           gyros_dumbbell_x
                                                               gyros_dumbbell_y
##
           : 0.000
                       Min.
                             :
                                    0.00
                                           Min.
                                                  :-204.0000
                                                               Min.
                                                                      :-2.10000
   Min.
   1st Ou.: 3.885
                                   15.09
##
                        1st Ou.:
                                           1st Ou.: -0.0300
                                                               1st Ou.:-0.14000
   Median : 10.264
                        Median :
                                 105.35
                                           Median :
                                                      0.1300
                                                               Median : 0.03000
##
##
   Mean
           : 16.647
                        Mean
                              : 589.84
                                           Mean
                                                      0.1611
                                                               Mean
                                                                      : 0.04606
   3rd Qu.: 24.674
                        3rd Qu.: 608.79
                                                               3rd Qu.: 0.21000
                                           3rd Qu.:
                                                      0.3500
##
                                                      2.2200
                               :11467.91
##
   Max.
           :107.088
                       Max.
                                           Max.
                                                :
                                                               Max.
                                                                      :52.00000
##
   NA's
           :19216
                        NA's
                               :19216
##
    gyros_dumbbell_z accel_dumbbell_x accel_dumbbell_y accel_dumbbell_z
                                               :-189.00
##
   Min.
           : -2.380
                     Min.
                            :-419.00
                                        Min.
                                                          Min.
                                                                :-334.00
   1st Qu.: -0.310
                     1st Qu.: -50.00
                                        1st Qu.: -8.00
                                                          1st Qu.:-142.00
##
   Median : -0.130
                     Median : -8.00
                                        Median : 41.50
##
                                                          Median : -1.00
   Mean : -0.129
                     Mean : -28.62
                                        Mean : 52.63
                                                          Mean : -38.32
##
##
    3rd Qu.: 0.030
                      3rd Qu.: 11.00
                                        3rd Qu.: 111.00
                                                          3rd Qu.: 38.00
##
   Max.
         :317.000
                      Max.
                            : 235.00
                                        Max.
                                               : 315.00
                                                          Max.
                                                                : 318.00
##
##
   magnet_dumbbell_x magnet_dumbbell_y magnet_dumbbell_z roll_forearm
   Min.
         :-643.0
                     Min. :-3600
                                        Min.
                                               :-262.00
                                                          Min. :-180.0000
##
##
   1st Qu.:-535.0
                     1st Qu.: 231
                                        1st Qu.: -45.00
                                                          1st Ou.: -0.7375
##
   Median :-479.0
                     Median :
                                311
                                        Median : 13.00
                                                          Median : 21.7000
   Mean
         :-328.5
##
                     Mean
                            :
                                221
                                        Mean : 46.05
                                                          Mean
                                                                : 33.8265
    3rd Qu.:-304.0
                                390
                                        3rd Qu.: 95.00
                                                          3rd Qu.: 140.0000
##
                     3rd Qu.:
         : 592.0
                                        Max.
                                               : 452.00
                                                                : 180.0000
##
   Max.
                     Max.
                            :
                                633
                                                          Max.
##
                     yaw_forearm
##
   pitch forearm
                                       kurtosis_roll_forearm
##
   Min.
          :-72.50
                     Min.
                            :-180.00
                                       Min.
                                              :-1.879
   1st Qu.: 0.00
                     1st Qu.: -68.60
##
                                       1st Qu.:-1.398
   Median: 9.24
                     Median: 0.00
                                       Median :-1.119
##
##
   Mean
          : 10.71
                     Mean
                          : 19.21
                                       Mean
                                              :-0.689
    3rd Qu.: 28.40
                     3rd Qu.: 110.00
                                       3rd Qu.:-0.618
##
##
   Max.
           : 89.80
                     Max.
                            : 180.00
                                       Max.
                                              :40.060
                                              :19300
##
                                       NA's
   kurtosis_picth_forearm kurtosis_yaw_forearm skewness_roll_forearm
##
##
   Min.
           :-2.098
                           Mode:logical
                                                Min.
                                                       :-2.297
   1st Qu.:-1.376
                           NA's:19622
                                                1st Qu.:-0.402
##
##
   Median :-0.890
                                                Median : 0.003
##
   Mean
           : 0.419
                                                Mean
                                                       :-0.009
   3rd Qu.: 0.054
                                                3rd Qu.: 0.370
##
##
   Max.
          :33.626
                                                       : 5.856
                                                Max.
##
   NA's
           :19301
                                                NA's
                                                       :19299
    skewness pitch forearm skewness yaw forearm max roll forearm max picth forearm
##
   Min.
           :-5.241
                           Mode:logical
                                                Min.
                                                       :-66.60
                                                                 Min.
                                                                        :-151.00
##
   1st Qu.:-0.881
                           NA's:19622
                                                1st Qu.: 0.00
                                                                 1st Qu.:
                                                                            0.00
##
##
   Median :-0.156
                                                Median : 26.80
                                                                 Median : 113.00
   Mean
         :-0.223
                                                       : 24.49
                                                                        : 81.49
##
                                                Mean
                                                                 Mean
##
    3rd Qu.: 0.514
                                                3rd Qu.: 45.95
                                                                 3rd Qu.: 174.75
##
   Max.
           : 4.464
                                                Max.
                                                       : 89.80
                                                                 Max.
                                                                        : 180.00
   NA's
                                                NA's
##
           :19301
                                                       :19216
                                                                 NA's
                                                                        :19216
   max yaw forearm
                    min roll forearm
                                       min pitch forearm min yaw forearm
##
                            :-72.500
##
   Min.
           :-1.900
                     Min.
                                       Min.
                                              :-180.00
                                                         Min.
                                                                :-1.900
##
   1st Qu.:-1.400
                     1st Qu.: -6.075
                                       1st Qu.:-175.00
                                                         1st Qu.:-1.400
##
   Median :-1.100
                     Median : 0.000
                                       Median : -61.00
                                                         Median :-1.100
##
   Mean
           :-0.689
                     Mean
                           : -0.167
                                       Mean
                                              : -57.57
                                                         Mean
                                                                :-0.689
   3rd Qu.:-0.600
                     3rd Qu.: 12.075
                                       3rd Qu.:
##
                                                  0.00
                                                         3rd Qu.:-0.600
                     Max.
                                                         Max.
##
   Max.
           :40.100
                            : 62.100
                                       Max.
                                              : 167.00
                                                                :40.100
##
   NA's
           :19300
                     NA's
                            :19216
                                       NA's
                                              :19216
                                                         NA's
                                                                :19300
    amplitude roll forearm amplitude pitch forearm amplitude yaw forearm
```

```
##
   Min.
          : 0.000
                          Min.
                                 : 0.0
                                                  Min.
                                                         :0
##
   1st Qu.: 1.125
                          1st Qu.: 2.0
                                                  1st Qu.:0
##
   Median : 17.770
                          Median: 83.7
                                                  Median:0
##
   Mean
         : 24.653
                          Mean
                                :139.1
                                                  Mean
                                                         :0
##
    3rd Qu.: 39.875
                          3rd Qu.:350.0
                                                  3rd Qu.:0
##
   Max.
          :126.000
                          Max.
                                 :360.0
                                                  Max.
                                                         :0
   NA's
          :19216
                          NA's
                                                  NA's
##
                                 :19216
                                                         :19300
   total_accel_forearm var_accel_forearm avg_roll_forearm
                                                            stddev_roll_forearm
##
##
   Min. : 0.00
                       Min.
                             : 0.000
                                         Min. :-177.234
                                                            Min. : 0.000
##
   1st Qu.: 29.00
                       1st Qu.: 6.759
                                         1st Qu.: -0.909
                                                            1st Qu.: 0.428
   Median : 36.00
                       Median : 21.165
##
                                         Median : 11.172
                                                            Median : 8.030
   Mean
         : 34.72
                             : 33.502
                                              : 33.165
                                                                  : 41.986
##
                       Mean
                                         Mean
                                                            Mean
##
   3rd Qu.: 41.00
                       3rd Qu.: 51.240
                                         3rd Qu.: 107.132
                                                            3rd Qu.: 85.373
##
   Max.
          :108.00
                       Max.
                              :172.606
                                         Max.
                                               : 177.256
                                                            Max.
                                                                   :179.171
##
                       NA's
                              :19216
                                         NA's
                                                :19216
                                                            NA's
                                                                   :19216
##
   var roll forearm
                      avg pitch forearm stddev pitch forearm var pitch forearm
   Min.
          :
               0.00
                      Min.
                             :-68.17
                                        Min.
                                               : 0.000
                                                             Min.
                                                                   :
                                                                       0.000
##
##
   1st Qu.:
               0.18
                      1st Qu.: 0.00
                                        1st Qu.: 0.336
                                                             1st Qu.:
                                                                        0.113
##
   Median :
              64.48
                      Median : 12.02
                                        Median : 5.516
                                                             Median : 30.425
##
   Mean
          : 5274.10
                      Mean : 11.79
                                        Mean
                                               : 7.977
                                                             Mean
                                                                    : 139.593
##
   3rd Qu.: 7289.08
                      3rd Qu.: 28.48
                                        3rd Qu.:12.866
                                                             3rd Qu.: 165.532
   Max.
          :32102.24
                      Max.
                             : 72.09
                                        Max.
                                                             Max.
                                                                    :2279.617
##
                                               :47.745
   NA's
          :19216
                      NA's
                             :19216
                                        NA's
                                               :19216
                                                             NA's
                                                                    :19216
##
   avg_yaw_forearm
                     stddev_yaw_forearm var_yaw_forearm
                                                           gyros_forearm_x
##
##
   Min.
          :-155.06
                     Min.
                            : 0.000
                                        Min.
                                                    0.00
                                                           Min.
                                                                 :-22.000
                                               :
##
   1st Qu.: -26.26
                     1st Qu.: 0.524
                                        1st Qu.:
                                                    0.27
                                                           1st Qu.: -0.220
##
   Median :
              0.00
                     Median : 24.743
                                        Median : 612.21
                                                           Median : 0.050
         : 18.00
                            : 44.854
                                                                : 0.158
##
   Mean
                     Mean
                                        Mean
                                              : 4639.85
                                                           Mean
   3rd Qu.: 85.79
                                        3rd Qu.: 7368.41
##
                     3rd Qu.: 85.817
                                                           3rd Qu.: 0.560
##
   Max.
         : 169.24
                     Max.
                            :197.508
                                        Max.
                                               :39009.33
                                                           Max.
                                                                  : 3.970
   NA's
          :19216
                     NA's
                            :19216
                                        NA's
                                               :19216
##
##
    gyros_forearm_y
                       gyros_forearm_z
                                          accel_forearm_x
                                                            accel_forearm_y
        : -7.02000
                       Min. : -8.0900
                                          Min. :-498.00
##
   Min.
                                                           Min. :-632.0
                       1st Qu.: -0.1800
   1st Qu.: -1.46000
                                                           1st Qu.: 57.0
##
                                          1st Qu.:-178.00
##
   Median : 0.03000
                       Median : 0.0800
                                          Median : -57.00
                                                          Median : 201.0
   Mean
         : 0.07517
                             : 0.1512
                                                : -61.65
                                                            Mean
                                                                 : 163.7
##
                       Mean
                                          Mean
                                          3rd Qu.: 76.00
                                                            3rd Qu.: 312.0
##
    3rd Qu.: 1.62000
                       3rd Qu.: 0.4900
##
   Max.
         :311.00000
                       Max.
                             :231.0000
                                          Max.
                                                 : 477.00
                                                            Max.
                                                                  : 923.0
##
##
   accel_forearm_z
                     magnet_forearm_x magnet_forearm_y magnet_forearm_z classe
##
   Min.
          :-446.00
                     Min.
                           :-1280.0
                                       Min.
                                              :-896.0
                                                        Min.
                                                               :-973.0
                                                                         A:5580
                     1st Qu.: -616.0
   1st Ou.:-182.00
                                                        1st Qu.: 191.0
##
                                       1st Ou.:
                                                  2.0
                                                                         B:3797
##
   Median : -39.00
                     Median : -378.0
                                       Median : 591.0
                                                        Median : 511.0
                                                                         C:3422
          : -55.29
                            : -312.6
##
   Mean
                     Mean
                                       Mean
                                              : 380.1
                                                        Mean
                                                              : 393.6
                                                                         D:3216
    3rd Ou.: 26.00
                     3rd Qu.: -73.0
                                       3rd Qu.: 737.0
                                                        3rd Qu.: 653.0
##
                                                                         E:3607
##
   Max.
          : 291.00
                     Max. : 672.0
                                       Max.
                                              :1480.0
                                                        Max.
                                                               :1090.0
##
```

```
## 'data.frame': 19622 obs. of 160 variables:
                           : int 1 2 3 4 5 6 7 8 9 10 ...
## $ X
                           : Factor w/ 6 levels "adelmo", "carlitos",..: 2 2 2 2 2 2 2 2 2
## $ user_name
2 ...
## $ raw timestamp part 1
                           : int 1323084231 1323084231 1323084231 1323084232 1323084232 1
323084232 1323084232 1323084232 1323084232 ...
## $ raw_timestamp_part_2
                          : int 788290 808298 820366 120339 196328 304277 368296 440390
484323 484434 ...
                           : Factor w/ 20 levels "02/12/2011 13:32",..: 9 9 9 9 9 9 9 9 9
## $ cvtd timestamp
9 ...
## $ new_window
                           : Factor w/ 2 levels "no", "yes": 1 1 1 1 1 1 1 1 1 1 ...
## $ num window
                           : int 11 11 11 12 12 12 12 12 12 12 ...
## $ roll_belt
                           : num 1.41 1.41 1.42 1.48 1.48 1.45 1.42 1.42 1.43 1.45 ...
                           : num 8.07 8.07 8.07 8.05 8.07 8.06 8.09 8.13 8.16 8.17 ...
## $ pitch_belt
## $ yaw_belt
                                 -94.4 -94.4 -94.4 -94.4 -94.4 -94.4 -94.4 -94.4 -9
                           : num
4.4 ...
## $ total_accel_belt
                           : int 3 3 3 3 3 3 3 3 3 ...
## $ kurtosis_roll_belt
                           : num NA NA NA NA NA NA NA NA NA ...
## $ kurtosis_picth_belt
                           : num NA NA NA NA NA NA NA NA NA ...
                           : logi NA NA NA NA NA NA ...
## $ kurtosis_yaw_belt
                           : num NA ...
## $ skewness roll belt
                                 NA NA NA NA NA NA NA NA NA ...
## $ skewness_roll_belt.1
                           : num
  $ skewness_yaw_belt
                           : logi NA NA NA NA NA NA ...
##
##
  $ max_roll_belt
                           : num
                                 NA ...
                                 NA ...
## $ max picth belt
                           : int
##
  $ max yaw belt
                           : num
                                 NA NA NA NA NA NA NA NA NA ...
## $ min_roll_belt
                                 NA NA NA NA NA NA NA NA NA ...
                           : num
##
   $ min_pitch_belt
                           : int
                                 NA NA NA NA NA NA NA NA NA ...
##
  $ min yaw belt
                                 NA ...
                           : num
                                 NA ...
## $ amplitude_roll_belt
                           : num
##
  $ amplitude pitch belt
                           : int
                                  NA NA NA NA NA NA NA NA NA ...
                                 NA NA NA NA NA NA NA NA NA ...
## $ amplitude_yaw_belt
                           : num
## $ var_total_accel_belt
                           : num
                                 NA NA NA NA NA NA NA NA NA ...
                                 NA ...
##
  $ avg_roll_belt
                           : num
                                 NA ...
## $ stddev_roll_belt
                           : num
## $ var_roll_belt
                           : num
                                  NA NA NA NA NA NA NA NA NA ...
## $ avg pitch belt
                                  NA NA NA NA NA NA NA NA NA ...
                           : num
                                  NA NA NA NA NA NA NA NA NA ...
##
   $ stddev pitch belt
                           : num
                                  NA NA NA NA NA NA NA NA NA ...
##
  $ var pitch belt
                           : num
## $ avg_yaw_belt
                           : num
                                  NA NA NA NA NA NA NA NA NA ...
##
  $ stddev_yaw_belt
                           : num
                                  NA NA NA NA NA NA NA NA NA ...
  $ var_yaw_belt
                                  NA NA NA NA NA NA NA NA NA ...
##
                           : num
                                  ##
   $ gyros belt x
                           : num
##
  $ gyros belt y
                           : num
                                  0 0 0 0 0.02 0 0 0 0 0 ...
## $ gyros_belt_z
                                  -0.02 -0.02 -0.02 -0.03 -0.02 -0.02 -0.02 -0.02 -0.02 0
                           : num
. . .
## $ accel belt x
                                 -21 -22 -20 -22 -21 -21 -22 -22 -20 -21 ...
                           : int
##
   $ accel belt y
                           : int
                                 4 4 5 3 2 4 3 4 2 4 ...
## $ accel belt z
                           : int 22 22 23 21 24 21 21 21 24 22 ...
## $ magnet belt x
                           : int
                                 -3 -7 -2 -6 -6 0 -4 -2 1 -3 ...
                           : int 599 608 600 604 600 603 599 603 602 609 ...
## $ magnet belt y
## $ magnet belt z
                           : int
                                  -313 -311 -305 -310 -302 -312 -311 -313 -312 -308 ...
##
  $ roll arm
                                  : num
                                 22.5 22.5 22.5 22.1 22.1 22 21.9 21.8 21.7 21.6 ...
## $ pitch arm
                           : num
                                 ## $ yaw arm
                           : num
##
  $ total_accel_arm
                           : int
                                  34 34 34 34 34 34 34 34 ...
## $ var_accel_arm
                           : num NA NA NA NA NA NA NA NA NA ...
```

```
##
   $ avg_roll_arm
                             : num
                                    NA NA NA NA NA NA NA NA NA ...
   $ stddev_roll_arm
                                    NA NA NA NA NA NA NA NA NA ...
##
                             : num
##
   $ var roll arm
                                    NA ...
                             : num
##
   $ avg_pitch_arm
                                    NA NA NA NA NA NA NA NA NA ...
                             : num
                                    NA NA NA NA NA NA NA NA NA ...
##
   $ stddev_pitch_arm
                              num
##
   $ var_pitch_arm
                                    NA NA NA NA NA NA NA NA NA ...
                              num
   $ avg yaw arm
                                    NA NA NA NA NA NA NA NA NA ...
##
                               num
##
   $ stddev_yaw_arm
                                    NA NA NA NA NA NA NA NA NA ...
                              num
   $ var_yaw_arm
                                    NA NA NA NA NA NA NA NA NA ...
##
                              num
##
   $ gyros_arm_x
                                    num
   $ gyros arm y
                                    0 -0.02 -0.02 -0.03 -0.03 -0.03 -0.03 -0.02 -0.03 -0.03
. . .
##
   $ gyros_arm_z
                                    -0.02 -0.02 -0.02 0.02 0 0 0 0 -0.02 -0.02 ...
                             : num
                                    -288 -290 -289 -289 -289 -289 -289 -288 -288 ...
##
   $ accel_arm_x
                             : int
##
   $ accel_arm_y
                             : int
                                    109 110 110 111 111 111 111 111 109 110 ...
##
   $ accel arm z
                                    -123 -125 -126 -123 -123 -122 -125 -124 -122 -124 ...
                                    -368 -369 -368 -372 -374 -369 -373 -372 -369 -376 ...
##
   $ magnet_arm_x
                             : int
##
   $ magnet_arm_y
                             : int
                                    337 337 344 344 337 342 336 338 341 334 ...
                                    516 513 513 512 506 513 509 510 518 516 ...
##
   $ magnet_arm_z
                             : int
##
   $ kurtosis_roll_arm
                                    NA NA NA NA NA NA NA NA NA ...
                             : num
##
                                    NA NA NA NA NA NA NA NA NA ...
   $ kurtosis picth arm
                             : num
##
   $ kurtosis_yaw_arm
                                    NA NA NA NA NA NA NA NA NA ...
                               num
##
   $ skewness_roll_arm
                             : num
                                    NA NA NA NA NA NA NA NA NA ...
                                    NA NA NA NA NA NA NA NA NA ...
##
   $ skewness_pitch_arm
                             : num
##
   $ skewness_yaw_arm
                                    NA NA NA NA NA NA NA NA NA ...
                             : num
                                    NA NA NA NA NA NA NA NA NA ...
##
   $ max roll arm
                             : num
##
   $ max_picth_arm
                                    NA NA NA NA NA NA NA NA NA ...
                               num
##
   $ max yaw arm
                             : int
                                    NA NA NA NA NA NA NA NA NA ...
##
   $ min_roll_arm
                                    NA NA NA NA NA NA NA NA NA ...
                             : num
##
   $ min_pitch_arm
                                    NA NA NA NA NA NA NA NA NA ...
                             : num
                                    NA NA NA NA NA NA NA NA NA ...
##
   $ min_yaw_arm
                             : int
##
   $ amplitude_roll_arm
                                    NA NA NA NA NA NA NA NA NA ...
                             : num
##
   $ amplitude_pitch_arm
                             : num
                                    NA NA NA NA NA NA NA NA NA ...
##
   $ amplitude_yaw_arm
                                    NA NA NA NA NA NA NA NA NA ...
                             : int
##
   $ roll_dumbbell
                                    13.1 13.1 12.9 13.4 13.4 ...
                             : num
                                    -70.5 -70.6 -70.3 -70.4 -70.4 ...
##
   $ pitch_dumbbell
                             : num
##
   $ yaw dumbbell
                                    -84.9 -84.7 -85.1 -84.9 -84.9 ...
                               num
##
   $ kurtosis roll dumbbell
                                    NA NA NA NA NA NA NA NA NA ...
   $ kurtosis_picth_dumbbell :
##
                               num
                                    NA NA NA NA NA NA NA NA NA ...
##
   $ kurtosis_yaw_dumbbell
                              logi
                                     NA NA NA NA NA ...
##
   $ skewness roll dumbbell
                             : num
                                    NA ...
##
   $ skewness pitch dumbbell : num
                                    NA NA NA NA NA NA NA NA NA ...
   $ skewness yaw dumbbell
                             : logi
                                     NA NA NA NA NA ...
##
##
   $ max_roll_dumbbell
                             : num
                                    NA NA NA NA NA NA NA NA NA ...
##
   $ max picth dumbbell
                                    NA NA NA NA NA NA NA NA NA ...
                             : num
##
   $ max yaw dumbbell
                             : num
                                    NA NA NA NA NA NA NA NA NA ...
##
   $ min_roll_dumbbell
                             : num
                                    NA NA NA NA NA NA NA NA NA ...
   $ min pitch dumbbell
                             : num
                                    NA NA NA NA NA NA NA NA NA ...
##
   $ min yaw dumbbell
                              num
                                    NA NA NA NA NA NA NA NA NA ...
##
   $ amplitude roll dumbbell : num
                                    NA NA NA NA NA NA NA NA NA ...
     [list output truncated]
```

As we can see above, the data is made up of a lot of variables (160) and 19,622 observations for the training dataset and 20 for the testing one. The variable of interest, the output variable, is going to be "classe".

Taking a look at the structure of the data, one can see the huge amount of not available values, thus being necessary to exclude the columns containing only them.

```
training <- training[, colSums(is.na(training)) == 0]
testing <- testing[, colSums(is.na(testing)) == 0]</pre>
```

So now there are only 60 variables left for each dataset (that is, minus 100 variables).

str(training)

```
## 'data.frame':
                 19622 obs. of 60 variables:
## $ X
                       : int 1 2 3 4 5 6 7 8 9 10 ...
                       ## $ user_name
. . .
## $ raw timestamp part 1: int 1323084231 1323084231 1323084232 1323084232 1323084232
84232 1323084232 1323084232 1323084232 1323084232 ...
## $ raw_timestamp_part_2: int 788290 808298 820366 120339 196328 304277 368296 440390 4843
23 484434 ...
                       : Factor w/ 20 levels "02/12/2011 13:32",..: 9 9 9 9 9 9 9 9 9 9 9
## $ cvtd_timestamp
## $ new_window
                       : Factor w/ 2 levels "no", "yes": 1 1 1 1 1 1 1 1 1 1 ...
## $ num window
                            11 11 11 12 12 12 12 12 12 12 ...
                       : int
## $ roll_belt
                       : num
                             1.41 1.41 1.42 1.48 1.48 1.45 1.42 1.42 1.43 1.45 ...
## $ pitch_belt
                             8.07 8.07 8.07 8.05 8.07 8.06 8.09 8.13 8.16 8.17 ...
                       : num
## $ yaw_belt
                             -94.4 -94.4 -94.4 -94.4 -94.4 -94.4 -94.4 -94.4 -94.4
                       : num
. . .
## $ total accel belt
                       : int
                            3 3 3 3 3 3 3 3 3 ...
## $ gyros_belt_x
                       : num
                             : num
## $ gyros_belt_y
                             0 0 0 0 0.02 0 0 0 0 0 ...
                             -0.02 -0.02 -0.02 -0.03 -0.02 -0.02 -0.02 -0.02 -0.02 0 ...
## $ gyros_belt_z
                       : num
## $ accel belt x
                       : int
                             -21 -22 -20 -22 -21 -21 -22 -22 -20 -21 ...
## $ accel_belt_y
                            4 4 5 3 2 4 3 4 2 4 ...
                       : int
## $ accel_belt_z
                       : int
                             22 22 23 21 24 21 21 21 24 22 ...
## $ magnet_belt_x
                       : int
                            -3 -7 -2 -6 -6 0 -4 -2 1 -3 ...
                       : int 599 608 600 604 600 603 599 603 602 609 ...
## $ magnet belt y
## $ magnet belt z
                       : int
                             -313 -311 -305 -310 -302 -312 -311 -313 -312 -308 ...
## $ roll arm
                             : num
## $ pitch_arm
                       : num
                             22.5 22.5 22.5 22.1 22.1 22 21.9 21.8 21.7 21.6 ...
## $ yaw arm
                       : num
                            ## $ total_accel_arm
                       : int 34 34 34 34 34 34 34 34 34 ...
  $ gyros_arm_x
##
                       : num
                             0 -0.02 -0.02 -0.03 -0.03 -0.03 -0.03 -0.02 -0.03 -0.03 ...
## $ gyros_arm_y
                       : num
## $ gyros_arm_z
                       : num
                             -0.02 -0.02 -0.02 0.02 0 0 0 0 -0.02 -0.02 ...
                            -288 -290 -289 -289 -289 -289 -289 -288 -288 ...
## $ accel_arm_x
                       : int
## $ accel_arm_y
                       : int 109 110 110 111 111 111 111 111 109 110 ...
## $ accel_arm_z
                       : int
                             -123 -125 -126 -123 -123 -122 -125 -124 -122 -124 ...
## $ magnet arm x
                       : int
                             -368 -369 -368 -372 -374 -369 -373 -372 -369 -376 ...
                             337 337 344 344 337 342 336 338 341 334 ...
##
  $ magnet arm y
                       : int
                            516 513 513 512 506 513 509 510 518 516 ...
## $ magnet arm z
                       : int
## $ roll_dumbbell
                       : num
                             13.1 13.1 12.9 13.4 13.4 ...
## $ pitch_dumbbell
                       : num
                             -70.5 -70.6 -70.3 -70.4 -70.4 ...
## $ yaw dumbbell
                             -84.9 -84.7 -85.1 -84.9 -84.9 ...
                       : num
  $ total accel dumbbell: int
                             37 37 37 37 37 37 37 37 37 ...
## $ gyros dumbbell x
                       : num
                             0000000000...
## $ gyros_dumbbell_y
                             -0.02 -0.02 -0.02 -0.02 -0.02 -0.02 -0.02 -0.02 -0.02
                       : num
. . .
## $ gyros dumbbell z
                       : num
                             0 0 0 -0.02 0 0 0 0 0 0 ...
  $ accel dumbbell x
                       : int
                             -234 -233 -232 -232 -233 -234 -232 -234 -232 -235 ...
## $ accel dumbbell y
                       : int
                            47 47 46 48 48 48 47 46 47 48 ...
## $ accel dumbbell z
                       : int
                             -271 -269 -270 -269 -270 -269 -270 -272 -269 -270 ...
##
  $ magnet dumbbell x
                       : int
                             -559 -555 -561 -552 -554 -558 -551 -555 -549 -558 ...
## $ magnet_dumbbell_y
                       : int
                             293 296 298 303 292 294 295 300 292 291 ...
## $ magnet dumbbell z
                             -65 -64 -63 -60 -68 -66 -70 -74 -65 -69 ...
                       : num
## $ roll forearm
                             28.4 28.3 28.3 28.1 28 27.9 27.9 27.8 27.7 27.7 ...
                       : num
## $ pitch forearm
                             -63.9 -63.9 -63.9 -63.9 -63.9 -63.8 -63.8 -63.8
                       : num
## $ yaw_forearm
                             : num
```

```
$ total accel forearm : int 36 36 36 36 36 36 36 36 36 ...
##
##
  $ gyros_forearm_x
                       : num
                             ## $ gyros_forearm_y
                        : num 0 0 -0.02 -0.02 0 -0.02 0 -0.02 0 0 ...
                             -0.02 -0.02 0 0 -0.02 -0.03 -0.02 0 -0.02 -0.02 ...
## $ gyros forearm z
                       : num
## $ accel_forearm_x
                       : int 192 192 196 189 189 193 195 193 193 190 ...
## $ accel_forearm_y
                       : int 203 203 204 206 206 203 205 205 204 205 ...
## $ accel forearm z
                       : int -215 -216 -213 -214 -214 -215 -215 -213 -214 -215 ...
## $ magnet_forearm_x
                       : int -17 -18 -18 -16 -17 -9 -18 -9 -16 -22 ...
## $ magnet_forearm_y
                       : num 654 661 658 658 655 660 659 660 653 656 ...
## $ magnet_forearm_z
                       : num
                              476 473 469 469 473 478 470 474 476 473 ...
                        : Factor w/ 5 levels "A", "B", "C", "D", ...: 1 1 1 1 1 1 1 1 1 1 ...
## $ classe
```

Taking a look at the structure of the data above, one can see that there are plenty of useless variables for the project (specific information about the elements involved in the experiment, but nothing to do with the performance of the participants, which is specifically what we want). In this sense, yet other variables may be excluded, such as those of the first seven columns.

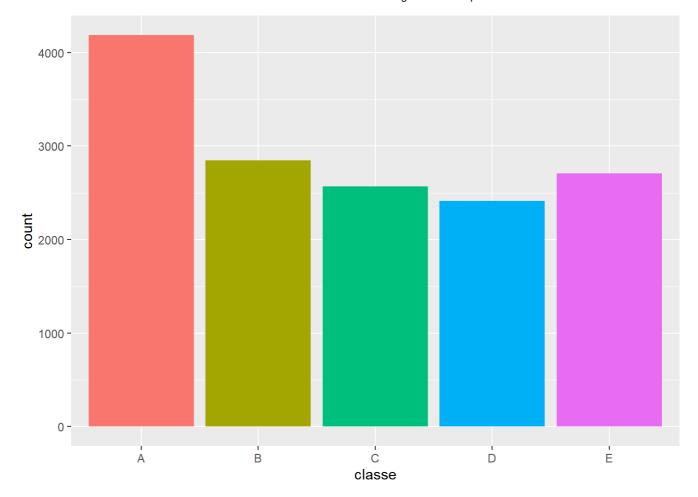
```
training <- training[, -c(1:7)]
testing <- testing[, -c(1:7)]</pre>
```

Having appropriately cleaned the data, it's time to partition the training dataset into 75% of training and the 25% left into testing, which is given as follows:

```
inTrain <- createDataPartition(y = training$classe, p = .75, list = F)
training_training <- training[inTrain, ]
training_testing <- training[-inTrain, ]</pre>
```

As one can see on the structure of the data above, the aforementioned outcome variable, "classe", consists of 5 levels (A, B, C, D, E). To get to know better the frequency of each classe, it's desirable to take a look at a plot.

```
ggplot(data = training_training) + geom_bar(mapping = aes(x = classe, fill = classe), show.le
gend = F)
```



This plot allows us to see that except for class A (according to specification), the common mistakes (the other classes) have approximately the same frequency.

### Decision tree

In order to assess the machine learning algorithm for prediction, decision tree method is used. This model was chosen because some of its pros are the ease of interpreting as well as the better performance in nonlinear settings.

```
model_tree <- rpart(classe ~ ., data = training_training, method = "class")
prediction_tree <- predict(model_tree, training_testing, type = "class")</pre>
```

For the sake of visualization, the resulting plot is as follows:

```
rpart.plot(model_tree, main = "Decision tree", extra = 102, under = T, faclen = 0, cex = .55)
```

#### **Decision tree** A B CDE A 4185 / 14718 A yes -roll\_belt < 131- no 4175 / 13483 pitch\_forearm < -34 $\mathbf{A}$ 3016 / 12320 B $\left( \mathbf{A} \right)$ magnet dumbbell y < 440 2963 / 10462 946 / 1858 A roll\_forearm < 124 (c)total\_a@\_\_\_13%mbbell >= 6 2643 / 6480 1319 / 3982 Amagnet\_dumbbell\_z < -25A ma Ct\_dumbbell\_D292roll\_belt >= -0.58 1492 / 2237 1151 / 4243 1131 / 2330 551 / 1652 magnet\_forearmarcel2\_E earm\_x >= -101 roll forearm >= -136 (c)yaw belt >= 169 1129 / 3666 362 / 1070 (D) magnet\_arm\_y >= 189 accel\_dumbbell\_y >= -40 857 / 3160 pitch\_belt < -43—D 847 / 2778 (c) roll\_belt >= 126 391 / 652 838 / 2126 magnet belt z < -323 Bitch belt >= 1 316 / 1344 acc A dumbbell E 28 291 / 846 224 / 498 yaw\_rearm rell-goumbbell < 53 291 / 618 magnet forearm z >= -68 C E © B (C) A B **(c)** A E (D) (B) (B) (A) (B) (E)

Though the plot has too much of information, we still can make use of the confusion matrix, so as to visualize the performance of the algorithm within the testing dataset.

1159 / 11**85**8 / 18**59**0 / 37**8**88 / 57**3**74 / 38203 / 2098 8 / 44280 / 38232 / 23**6**77 / 22**8**71 / 31**0**63 / 18**8**4 / 778**2**38 / 50**6**51 / 18**7**3 / 21**2**48 / 45814 / 61405 / 5**2**25 / 110296 / 2089 8 / 54225 / 1235 8% 13% 3% 4% 3% 1% 3% 3% 2% 2% 2% 1% 5% 3% 1% 15% 3% 4% 4% 8% 1% 4% 8% 1% 4% 8%

confusionMatrix(prediction\_tree, training\_testing\$classe)

```
## Confusion Matrix and Statistics
##
##
             Reference
## Prediction
                           C
                                D
                                     Ε
                 Α
                      В
##
            A 1235
                    157
                          16
                               50
                                    20
##
            В
                55
                    568
                          73
                               80
                                   102
                44 125
##
            C
                         690
                             118
                                   116
##
            D
                41
                     64
                          50
                              508
                                    38
##
            Ε
                20
                     35
                          26
                               48
                                   625
##
## Overall Statistics
##
##
                  Accuracy : 0.7394
##
                    95% CI: (0.7269, 0.7516)
       No Information Rate: 0.2845
##
##
       P-Value [Acc > NIR] : < 2.2e-16
##
##
                     Kappa: 0.6697
##
   Mcnemar's Test P-Value : < 2.2e-16
##
##
## Statistics by Class:
##
##
                        Class: A Class: B Class: C Class: D Class: E
## Sensitivity
                                            0.8070
                                                     0.6318
                          0.8853
                                   0.5985
                                                              0.6937
## Specificity
                          0.9307
                                   0.9216
                                            0.9005
                                                     0.9529
                                                              0.9678
## Pos Pred Value
                          0.8356
                                   0.6469
                                            0.6313
                                                     0.7247
                                                              0.8289
## Neg Pred Value
                          0.9533
                                   0.9054
                                            0.9567
                                                     0.9296
                                                              0.9335
## Prevalence
                          0.2845
                                   0.1935
                                            0.1743
                                                              0.1837
                                                     0.1639
## Detection Rate
                          0.2518
                                   0.1158
                                            0.1407
                                                     0.1036
                                                              0.1274
## Detection Prevalence
                          0.3014
                                   0.1790
                                            0.2229
                                                     0.1429
                                                              0.1538
## Balanced Accuracy
                                   0.7601
                                                     0.7924
                          0.9080
                                            0.8537
                                                              0.8307
```

So, all of biggest values in each column of the matrix coincide with the actual-prediction values.

#### Random Forest

In order to assess the machine learning algorithm for prediction, random forest method is used. This model was chosen because one of its pros is specifically the accuracy, which will be compared with that of the decision tree model.

That said, the modeling and its prediction are as follows:

```
model_rf <- randomForest(classe ~ ., data = training_training, method = "class")
prediction_rf <- predict(model_rf, training_testing, type = "class")</pre>
```

Just as we did before, the confusion matrix is then provided.

```
confusionMatrix(prediction_rf, training_testing$classe)
```

```
## Confusion Matrix and Statistics
##
##
             Reference
## Prediction
                 Α
                            C
                                      Ε
##
            A 1395
                       3
##
            В
                 0
                    943
                           10
                                 0
                 0
                      3
                                 5
##
            C
                         844
##
            D
                 0
                      0
                            1
                               799
                                      0
##
                                    901
##
## Overall Statistics
##
##
                  Accuracy: 0.9955
##
                    95% CI: (0.9932, 0.9972)
       No Information Rate: 0.2845
##
##
       P-Value [Acc > NIR] : < 2.2e-16
##
##
                      Kappa: 0.9943
##
    Mcnemar's Test P-Value : NA
##
##
## Statistics by Class:
##
##
                        Class: A Class: B Class: C Class: D Class: E
## Sensitivity
                          1.0000
                                    0.9937
                                             0.9871
                                                       0.9938
                                                                1.0000
## Specificity
                          0.9991
                                    0.9975
                                             0.9980
                                                       0.9998
                                                                1.0000
## Pos Pred Value
                          0.9979
                                    0.9895
                                             0.9906
                                                       0.9988
                                                                1.0000
## Neg Pred Value
                          1.0000
                                    0.9985
                                             0.9973
                                                       0.9988
                                                                1.0000
## Prevalence
                          0.2845
                                    0.1935
                                             0.1743
                                                       0.1639
                                                                0.1837
## Detection Rate
                          0.2845
                                    0.1923
                                             0.1721
                                                       0.1629
                                                                0.1837
## Detection Prevalence
                          0.2851
                                    0.1943
                                             0.1737
                                                       0.1631
                                                                0.1837
## Balanced Accuracy
                          0.9996
                                    0.9956
                                             0.9926
                                                       0.9968
                                                                1.0000
```

So, one can see that all of the biggest values in each column coincide with the actual-prediction values of the dataset. Besides that, these values are much better than those of the first model.

# Which prediction model to choose?

As briefly outlined above, the confusion matrix indicates that the second model (Random Forest) overtly predicts better than the first one. Indeed, one can see that for the first model (Decision Tree) the accuracy is about 0.73 and the 95% confidence interval is (0.7269, 0.7516) whereas the second one is impressively 0.99 and its 95% confidence interval is (0.9932, 0.9972). In this sense, the Random Forest model is indisputably the chosen one. Also, the expected out-of-sample error is about 0.5%.

# Testing the algorithm with the provided testing dataset

Once selected the proper model, we are going to make use of the Random Forest model to make predictions out of the testing dataset:

```
finalprediction <- predict(model_rf, testing, type = "class")
finalprediction</pre>
```

## 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20

 $\hbox{\tt ## } \hbox{\tt B } \hbox{\tt A } \hbox{\tt B } \hbox{\tt A } \hbox{\tt A } \hbox{\tt E } \hbox{\tt D } \hbox{\tt B } \hbox{\tt A } \hbox{\tt A } \hbox{\tt B } \hbox{\tt C } \hbox{\tt B } \hbox{\tt A } \hbox{\tt E } \hbox{\tt E } \hbox{\tt A } \hbox{\tt B } \hbox{\tt B } \hbox{\tt B } \\$ 

## Levels: A B C D E