Qualitative Activity Recognition of Weight Lifting Exercises

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Synopis

In this asigment we aim to predict whether a physical excercise (Unilateral Dumbbell Biceps Curl) has been performed correctly or whether a well know mistake has been made. We have a training set created by recording the activities of 6 individuals each performing the excercise correctly and performing the excercise with one out of four known mistakes in sequence. Each recording has been labled with a 'class' variable where 'A' is the correct way of performing the excercise and 'B' through 'E' are the erroneous ways. Each excercise was recorded by 4 sensors attached to upper arm, wrist, waist and the dumbbell respectedly. Each sensor is measuring acceleration in three dimensions as well as rotation in three dimensional axes. We aim to train a model that can predict from each measurement to what 'classe' it belongs. With this model we would be able to provide real time feedback to the individual performing the excercise.

Data processing

Loading the data

We load the data. We suppress the immidiate conversion to factors as it seems to have some unwanted effect on this dataset. We'll convert the right columns to factor variables later on.

```
set.seed(12345)
training<-read.csv("pml-training.csv",stringsAsFactors = FALSE)
testing<-read.csv("pml-testing.csv",stringsAsFactors = FALSE)
```

Exploring the data

As a first step, let's get some very basic info about the dataset we've just read

```
print(dim(training))
```

```
## [1] 19622   160
```

```
head(training)
```

```
##   X user_name raw_timestamp_part_1 raw_timestamp_part_2   cvtd_timestamp
## 1 1  carlitos           1323084231               788290 05/12/2011 11:23
## 2 2  carlitos           1323084231               808298 05/12/2011 11:23
## 3 3  carlitos           1323084231               820366 05/12/2011 11:23
## 4 4  carlitos           1323084232               120339 05/12/2011 11:23
## 5 5  carlitos           1323084232               196328 05/12/2011 11:23
## 6 6  carlitos           1323084232               304277 05/12/2011 11:23
##   new_window num_window roll_belt pitch_belt yaw_belt total_accel_belt
## 1         no         11      1.41       8.07    -94.4                3
## 2         no         11      1.41       8.07    -94.4                3
```

```
## 3         no         11      1.42       8.07    -94.4                3
## 4         no         12      1.48       8.05    -94.4                3
## 5         no         12      1.48       8.07    -94.4                3
## 6         no         12      1.45       8.06    -94.4                3
##   kurtosis_roll_belt kurtosis_picth_belt kurtosis_yaw_belt
## 1
## 2
## 3
## 4
## 5
## 6
##   skewness_roll_belt skewness_roll_belt.1 skewness_yaw_belt max_roll_belt
## 1                                                                      NA
## 2                                                                      NA
## 3                                                                      NA
## 4                                                                      NA
## 5                                                                      NA
## 6                                                                      NA
##   max_picth_belt max_yaw_belt min_roll_belt min_pitch_belt min_yaw_belt
## 1             NA                        NA             NA
## 2             NA                        NA             NA
## 3             NA                        NA             NA
## 4             NA                        NA             NA
## 5             NA                        NA             NA
## 6             NA                        NA             NA
##   amplitude_roll_belt amplitude_pitch_belt amplitude_yaw_belt
## 1                  NA                   NA
## 2                  NA                   NA
## 3                  NA                   NA
## 4                  NA                   NA
## 5                  NA                   NA
## 6                  NA                   NA
##   var_total_accel_belt avg_roll_belt stddev_roll_belt var_roll_belt
## 1                   NA            NA               NA            NA
## 2                   NA            NA               NA            NA
## 3                   NA            NA               NA            NA
## 4                   NA            NA               NA            NA
## 5                   NA            NA               NA            NA
## 6                   NA            NA               NA            NA
##   avg_pitch_belt stddev_pitch_belt var_pitch_belt avg_yaw_belt
## 1             NA                NA             NA           NA
## 2             NA                NA             NA           NA
## 3             NA                NA             NA           NA
## 4             NA                NA             NA           NA
## 5             NA                NA             NA           NA
## 6             NA                NA             NA           NA
##   stddev_yaw_belt var_yaw_belt gyros_belt_x gyros_belt_y gyros_belt_z
## 1              NA           NA         0.00         0.00        -0.02
## 2              NA           NA         0.02         0.00        -0.02
## 3              NA           NA         0.00         0.00        -0.02
## 4              NA           NA         0.02         0.00        -0.03
## 5              NA           NA         0.02         0.02        -0.02
## 6              NA           NA         0.02         0.00        -0.02
##   accel_belt_x accel_belt_y accel_belt_z magnet_belt_x magnet_belt_y
```

```
## 1          -21            4           22            -3           599
## 2          -22            4           22            -7           608
## 3          -20            5           23            -2           600
## 4          -22            3           21            -6           604
## 5          -21            2           24            -6           600
## 6          -21            4           21             0           603
##   magnet_belt_z roll_arm pitch_arm yaw_arm total_accel_arm var_accel_arm
## 1          -313     -128      22.5    -161              34            NA
## 2          -311     -128      22.5    -161              34            NA
## 3          -305     -128      22.5    -161              34            NA
## 4          -310     -128      22.1    -161              34            NA
## 5          -302     -128      22.1    -161              34            NA
## 6          -312     -128      22.0    -161              34            NA
##   avg_roll_arm stddev_roll_arm var_roll_arm avg_pitch_arm stddev_pitch_arm
## 1           NA              NA           NA            NA                NA
## 2           NA              NA           NA            NA                NA
## 3           NA              NA           NA            NA                NA
## 4           NA              NA           NA            NA                NA
## 5           NA              NA           NA            NA                NA
## 6           NA              NA           NA            NA                NA
##   var_pitch_arm avg_yaw_arm stddev_yaw_arm var_yaw_arm gyros_arm_x
## 1            NA          NA             NA          NA        0.00
## 2            NA          NA             NA          NA        0.02
## 3            NA          NA             NA          NA        0.02
## 4            NA          NA             NA          NA        0.02
## 5            NA          NA             NA          NA        0.00
## 6            NA          NA             NA          NA        0.02
##   gyros_arm_y gyros_arm_z accel_arm_x accel_arm_y accel_arm_z magnet_arm_x
## 1        0.00       -0.02        -288         109        -123         -368
## 2       -0.02       -0.02        -290         110        -125         -369
## 3       -0.02       -0.02        -289         110        -126         -368
## 4       -0.03        0.02        -289         111        -123         -372
## 5       -0.03        0.00        -289         111        -123         -374
## 6       -0.03        0.00        -289         111        -122         -369
##   magnet_arm_y magnet_arm_z kurtosis_roll_arm kurtosis_picth_arm
## 1          337          516
## 2          337          513
## 3          344          513
## 4          344          512
## 5          337          506
## 6          342          513
##   kurtosis_yaw_arm skewness_roll_arm skewness_pitch_arm skewness_yaw_arm
## 1
## 2
## 3
## 4
## 5
## 6
##   max_roll_arm max_picth_arm max_yaw_arm min_roll_arm min_pitch_arm
## 1           NA            NA          NA           NA            NA
## 2           NA            NA          NA           NA            NA
## 3           NA            NA          NA           NA            NA
## 4           NA            NA          NA           NA            NA
## 5           NA            NA          NA           NA            NA
```

```
## 6           NA            NA          NA           NA            NA
##   min_yaw_arm amplitude_roll_arm amplitude_pitch_arm amplitude_yaw_arm
## 1          NA                 NA                  NA                NA
## 2          NA                 NA                  NA                NA
## 3          NA                 NA                  NA                NA
## 4          NA                 NA                  NA                NA
## 5          NA                 NA                  NA                NA
## 6          NA                 NA                  NA                NA
##   roll_dumbbell pitch_dumbbell yaw_dumbbell kurtosis_roll_dumbbell
## 1      13.05217      -70.49400    -84.87394
## 2      13.13074      -70.63751    -84.71065
## 3      12.85075      -70.27812    -85.14078
## 4      13.43120      -70.39379    -84.87363
## 5      13.37872      -70.42856    -84.85306
## 6      13.38246      -70.81759    -84.46500
##   kurtosis_picth_dumbbell kurtosis_yaw_dumbbell skewness_roll_dumbbell
## 1
## 2
## 3
## 4
## 5
## 6
##   skewness_pitch_dumbbell skewness_yaw_dumbbell max_roll_dumbbell
## 1                                                              NA
## 2                                                              NA
## 3                                                              NA
## 4                                                              NA
## 5                                                              NA
## 6                                                              NA
##   max_picth_dumbbell max_yaw_dumbbell min_roll_dumbbell min_pitch_dumbbell
## 1                 NA                                 NA                 NA
## 2                 NA                                 NA                 NA
## 3                 NA                                 NA                 NA
## 4                 NA                                 NA                 NA
## 5                 NA                                 NA                 NA
## 6                 NA                                 NA                 NA
##   min_yaw_dumbbell amplitude_roll_dumbbell amplitude_pitch_dumbbell
## 1                                       NA                       NA
## 2                                       NA                       NA
## 3                                       NA                       NA
## 4                                       NA                       NA
## 5                                       NA                       NA
## 6                                       NA                       NA
##   amplitude_yaw_dumbbell total_accel_dumbbell var_accel_dumbbell
## 1                                         37                NA
## 2                                         37                NA
## 3                                         37                NA
## 4                                         37                NA
## 5                                         37                NA
## 6                                         37                NA
##   avg_roll_dumbbell stddev_roll_dumbbell var_roll_dumbbell
## 1                NA                   NA                NA
## 2                NA                   NA                NA
## 3                NA                   NA                NA
```

```
## 4                NA                   NA                NA
## 5                NA                   NA                NA
## 6                NA                   NA                NA
##   avg_pitch_dumbbell stddev_pitch_dumbbell var_pitch_dumbbell
## 1                 NA                   NA                NA
## 2                 NA                   NA                NA
## 3                 NA                   NA                NA
## 4                 NA                   NA                NA
## 5                 NA                   NA                NA
## 6                 NA                   NA                NA
##   avg_yaw_dumbbell stddev_yaw_dumbbell var_yaw_dumbbell gyros_dumbbell_x
## 1               NA                  NA               NA                0
## 2               NA                  NA               NA                0
## 3               NA                  NA               NA                0
## 4               NA                  NA               NA                0
## 5               NA                  NA               NA                0
## 6               NA                  NA               NA                0
##   gyros_dumbbell_y gyros_dumbbell_z accel_dumbbell_x accel_dumbbell_y
## 1            -0.02             0.00             -234               47
## 2            -0.02             0.00             -233               47
## 3            -0.02             0.00             -232               46
## 4            -0.02            -0.02             -232               48
## 5            -0.02             0.00             -233               48
## 6            -0.02             0.00             -234               48
##   accel_dumbbell_z magnet_dumbbell_x magnet_dumbbell_y magnet_dumbbell_z
## 1             -271              -559               293               -65
## 2             -269              -555               296               -64
## 3             -270              -561               298               -63
## 4             -269              -552               303               -60
## 5             -270              -554               292               -68
## 6             -269              -558               294               -66
##   roll_forearm pitch_forearm yaw_forearm kurtosis_roll_forearm
## 1         28.4         -63.9       -153
## 2         28.3         -63.9       -153
## 3         28.3         -63.9       -152
## 4         28.1         -63.9       -152
## 5         28.0         -63.9       -152
## 6         27.9         -63.9       -152
##   kurtosis_picth_forearm kurtosis_yaw_forearm skewness_roll_forearm
## 1
## 2
## 3
## 4
## 5
## 6
##   skewness_pitch_forearm skewness_yaw_forearm max_roll_forearm
## 1                                                           NA
## 2                                                           NA
## 3                                                           NA
## 4                                                           NA
## 5                                                           NA
## 6                                                           NA
##   max_picth_forearm max_yaw_forearm min_roll_forearm min_pitch_forearm
## 1                NA                                NA                NA
```

```
## 2                NA                                NA                NA
## 3                NA                                NA                NA
## 4                NA                                NA                NA
## 5                NA                                NA                NA
## 6                NA                                NA                NA
##   min_yaw_forearm amplitude_roll_forearm amplitude_pitch_forearm
## 1                                    NA                      NA
## 2                                    NA                      NA
## 3                                    NA                      NA
## 4                                    NA                      NA
## 5                                    NA                      NA
## 6                                    NA                      NA
##   amplitude_yaw_forearm total_accel_forearm var_accel_forearm
## 1                                        36               NA
## 2                                        36               NA
## 3                                        36               NA
## 4                                        36               NA
## 5                                        36               NA
## 6                                        36               NA
##   avg_roll_forearm stddev_roll_forearm var_roll_forearm avg_pitch_forearm
## 1               NA                  NA               NA                NA
## 2               NA                  NA               NA                NA
## 3               NA                  NA               NA                NA
## 4               NA                  NA               NA                NA
## 5               NA                  NA               NA                NA
## 6               NA                  NA               NA                NA
##   stddev_pitch_forearm var_pitch_forearm avg_yaw_forearm
## 1                   NA                NA              NA
## 2                   NA                NA              NA
## 3                   NA                NA              NA
## 4                   NA                NA              NA
## 5                   NA                NA              NA
## 6                   NA                NA              NA
##   stddev_yaw_forearm var_yaw_forearm gyros_forearm_x gyros_forearm_y
## 1                 NA              NA            0.03            0.00
## 2                 NA              NA            0.02            0.00
## 3                 NA              NA            0.03           -0.02
## 4                 NA              NA            0.02           -0.02
## 5                 NA              NA            0.02            0.00
## 6                 NA              NA            0.02           -0.02
##   gyros_forearm_z accel_forearm_x accel_forearm_y accel_forearm_z
## 1           -0.02             192             203            -215
## 2           -0.02             192             203            -216
## 3            0.00             196             204            -213
## 4            0.00             189             206            -214
## 5           -0.02             189             206            -214
## 6           -0.03             193             203            -215
##   magnet_forearm_x magnet_forearm_y magnet_forearm_z classe
## 1              -17              654              476      A
## 2              -18              661              473      A
## 3              -18              658              469      A
## 4              -16              658              469      A
## 5              -17              655              473      A
## 6               -9              660              478      A
```

From the first check it's obvious that not all colums seem to contain data. Further inspection reveals that the dataset contains two distinct kind of rows. The records labeled new_window = 'no' contain only raw data from the sensors, while the records labeled 'yes' also contain statistical derivatives from one complete excersize.

```
# check how a 'statistical' column relates tot the 'new_window' variable
print(table(training$new_window,training$kurtosis_roll_belt==""))
```

```
##
##       FALSE  TRUE
##   no      0 19216
##   yes   406     0
```

```
# check if the test set contains any 'new_window' rows
print(table(testing$new_window))
```

```
##
## no
## 20
```

Since the test set contains only records where new_window = 'no' we cannot use this information in our prediction. For this reason we will get rid of the columns that only have information for the 'yes' records. We will also get rid of the timestamp information, as this would result in recognizing 'when' the activity was performed rather than 'how'.

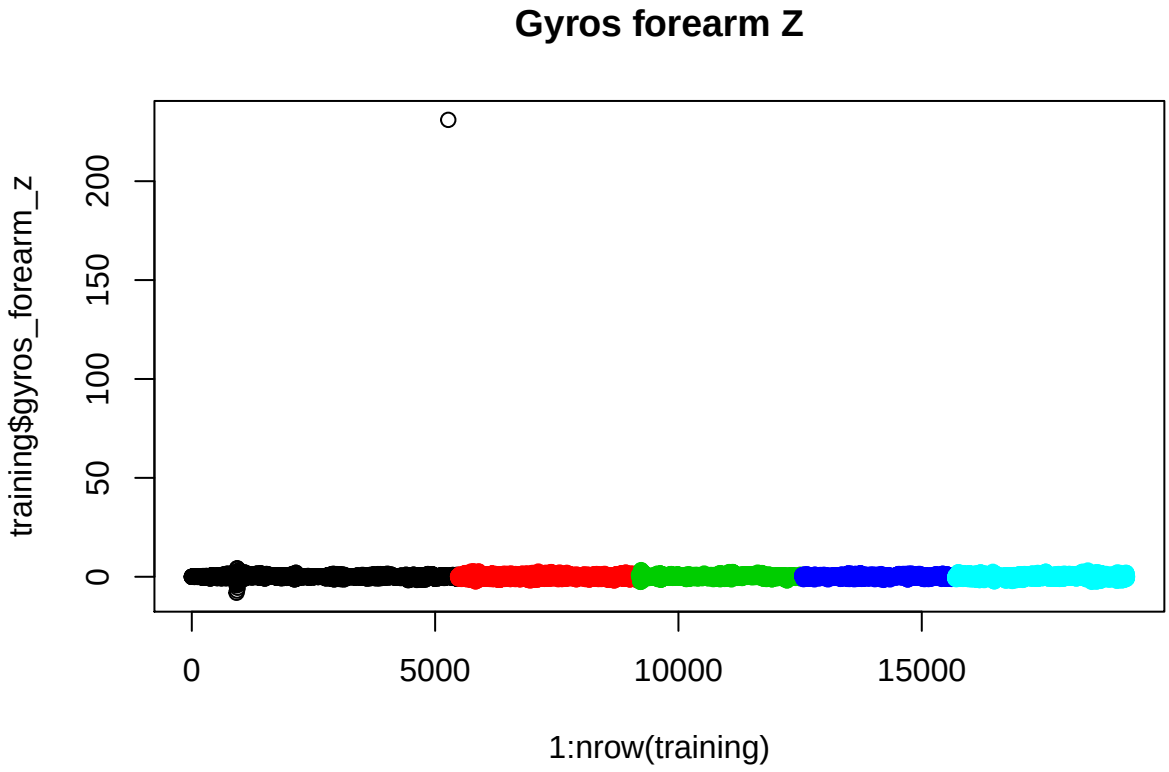
Cleaning the Data

Since the test set has only new_window = "no" records we can kick the "yes" records out of the training set and after that, get rid of all the columns that have a constant value or all NA's

```
training<-training[training$new_window=="no",]

na_cols<-which(colSums(is.na(training))==nrow(training))

blank_cols<-which(colSums(training[,]=="")==nrow(training))

training<-training[,c(-na_cols,-blank_cols)]
testing<-testing[,c(-na_cols,-blank_cols)]

#convert uses_name and classe to factor variables
training$user_name<-factor(training$user_name)
testing$user_name<-factor(testing$user_name,levels=levels(training$user_name))
training$classe<-factor(training$classe)

#get rid of all timestamp related columns
training$X<-NULL; testing$X<-NULL
training$raw_timestamp_part_1<-NULL; testing$raw_timestamp_part_1<-NULL
training$raw_timestamp_part_2<-NULL; testing$raw_timestamp_part_2<-NULL
training$cvtd_timestamp<-NULL; testing$cvtd_timestamp<-NULL
training$new_window<-NULL; testing$new_window<-NULL
training$num_window<-NULL; testing$num_window<-NULL
```

Finally, exploratory data analyses shows that there are some outliers. For instance if we look at the gyros_forearm_z column:

```
plot(1:nrow(training),training$gyros_forearm_z,col=training$classe); title("Gyros forearm Z")
```



There is a single outlier with a value above 300. We'll delete that one from the training set

```
which(training$gyros_forearm_z>200)
```

```
## [1] 5270
```

```
#record 5270 is an outlier, get rid of it
training<-training[-5270,]
```

Training the model

Model selection

From the nature of this experiment, it seems probable that the classification result will not have a linear dependency of the sensor outputs. For this case a Random Forest seem to be a proper model. We'll train a Random Forest model with 5 fold cross validation to get a predicited value for our out of set prediction error.

Training the model

First we load the nescessary libraries and set up the laptop for multithreading to reduce run time.

```
library(caret)
library(parallel)
```

```
library(doParallel)
library(beepr)
cluster <- makeCluster(detectCores() - 1) # convention to leave 1 core for OS
registerDoParallel(cluster)
```

Now train the model with 5 fold cross validation

```
fitControl <- trainControl(method = "cv",
                           number = 5,
                           allowParallel = TRUE)
fit <- caret::train(classe~.-user_name, method="rf",data=training,trControl = fitControl)
beep()
```

And check the results:

```
print(fit)
```

```
## Random Forest
##
## 19215 samples
##    53 predictor
##     5 classes: 'A', 'B', 'C', 'D', 'E'
##
## No pre-processing
## Resampling: Cross-Validated (5 fold)
## Summary of sample sizes: 15373, 15373, 15371, 15371, 15372
## Resampling results across tuning parameters:
##
##   mtry  Accuracy   Kappa
##    2    0.9940152  0.9924284
##   27    0.9941191  0.9925600
##   52    0.9889672  0.9860421
##
## Accuracy was used to select the optimal model using the largest value.
## The final value used for the model was mtry = 27.
```

```
print(fit$resample)
```

```
##    Accuracy     Kappa Resample
## 1 0.9927121 0.9907794    Fold1
## 2 0.9927159 0.9907840    Fold3
## 3 0.9945341 0.9930851    Fold2
## 4 0.9950559 0.9937456    Fold5
## 5 0.9955775 0.9944056    Fold4
```

```
print(confusionMatrix.train(fit))
```

```
## Cross-Validated (5 fold) Confusion Matrix
##
## (entries are percentual average cell counts across resamples)
##
##           Reference
## Prediction    A    B    C    D    E
##          A 28.4  0.1  0.0  0.0  0.0
##          B  0.0 19.2  0.1  0.0  0.0
##          C  0.0  0.0 17.3  0.2  0.0
##          D  0.0  0.0  0.1 16.2  0.0
```

```
##          E  0.0  0.0  0.0  0.0 18.3
##
##  Accuracy (average) : 0.9941
```

The results are good, showing that results can be predicted with over 99% accurancy

Applying the final model to the test set

Finally we make predictions to the test set. For this case, we retrain the model over the entire training set to get a slighty higher reliability. We train the model and check the results

```
fitControl <- trainControl(method = "boot",
                           number = 1,
                           allowParallel = TRUE)

fitFinal <- train(classe~., method="rf",data=training,trControl = fitControl)
beep()
fitFinal
```

```
## Random Forest
##
## 19215 samples
##    53 predictor
##     5 classes: 'A', 'B', 'C', 'D', 'E'
##
## No pre-processing
## Resampling: Bootstrapped (1 reps)
## Summary of sample sizes: 19215
## Resampling results across tuning parameters:
##
##   mtry  Accuracy   Kappa
##    2    0.9938668  0.9922353
##   29    0.9920126  0.9898890
##   57    0.9833119  0.9788757
##
## Accuracy was used to select the optimal model using the largest value.
## The final value used for the model was mtry = 2.
```

Predict on the test set:

```
testpredict<-predict(fitFinal,newdata = testing)
testpredict
```

```
##  [1] B A B A A E D B A A B C B A E E A B B B
## Levels: A B C D E
```

(Don't forget to close the multithreading)

```
stopCluster(cluster)
registerDoSEQ()
```