CourseProject

August 25, 2021

1 Course Project

1.1 Background

Using devices such as Jawbone Up, Nike FuelBand, and Fitbit it is now possible to collect a large amount of data about personal activity relatively inexpensively. These type of devices are part of the quantified self movement – a group of enthusiasts who take measurements about themselves regularly to improve their health, to find patterns in their behavior, or because they are tech geeks. One thing that people regularly do is quantify how much of a particular activity they do, but they rarely quantify how well they do it. In this project, your goal will be to use data from accelerometers on the belt, forearm, arm, and dumbell of 6 participants. They were asked to perform barbell lifts correctly and incorrectly in 5 different ways. More information is available from the website here: http://groupware.les.inf.puc-rio.br/har (see the section on the Weight Lifting Exercise Dataset).

1.2 Data

The training data for this project are available here:

https://d396qusza40orc.cloudfront.net/predmachlearn/pml-training.csv

The test data are available here:

https://d396qusza40orc.cloudfront.net/predmachlearn/pml-testing.csv

The data for this project come from this source: http://groupware.les.inf.puc-rio.br/har. If you use the document you create for this class for any purpose please cite them as they have been very generous in allowing their data to be used for this kind of assignment.

1.3 What you should submit

The goal of your project is to predict the manner in which they did the 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.

1.4 Peer Review Portion

Your submission for the Peer Review portion should consist of a link to a Github repo with your R markdown and compiled HTML file describing your analysis. Please constrain the text of the writeup to $<$ 2000 words and the number of figures to be less than 5. It will make it easier for the

graders if you submit a repo with a gh-pages branch so the HTML page can be viewed online (and you always want to make it easy on graders :-).

1.5 Course Project Prediction Quiz Portion

Apply your machine learning algorithm to the 20 test cases available in the test data above and submit your predictions in appropriate format to the Course Project Prediction Quiz for automated grading.

1.6 Reproducibility

Due to security concerns with the exchange of R code, your code will not be run during the evaluation by your classmates. Please be sure that if they download the repo, they will be able to view the compiled HTML version of your analysis.

1.7 Exploratory Data Analysis

[1]:
```
library(caret)
library(rpart)
library(rpart.plot)
library(RColorBrewer)
library(randomForest)
library(gbm)
```

```
Loading required package: lattice

Loading required package: ggplot2

randomForest 4.6-14

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


Attaching package: 'randomForest'


The following object is masked from 'package:ggplot2':

    margin


Loaded gbm 2.1.8
```

[2]:
```
training_data <- read.csv('pml-training.csv')
testing_data <- read.csv('pml-testing.csv')
```

[3]:
```
head(training_data)
```

A data.frame: 6 × 160

	X <int>	user_name <chr>	raw_timestamp_part_1 <int>	raw_timestamp_part_2 <int>	cvtd_tim <chr>
1	1	carlitos	1323084231	788290	05/12/20
2	2	carlitos	1323084231	808298	05/12/20
3	3	carlitos	1323084231	820366	05/12/20
4	4	carlitos	1323084232	120339	05/12/20
5	5	carlitos	1323084232	196328	05/12/20
6	6	carlitos	1323084232	304277	05/12/20

[4]:
```
head(testing_data)
```

A data.frame: 6 × 160

	X <int>	user_name <chr>	raw_timestamp_part_1 <int>	raw_timestamp_part_2 <int>	cvtd_tim <chr>
1	1	pedro	1323095002	868349	05/12/20
2	2	jeremy	1322673067	778725	30/11/20
3	3	jeremy	1322673075	342967	30/11/20
4	4	adelmo	1322832789	560311	02/12/20
5	5	eurico	1322489635	814776	28/11/20
6	6	jeremy	1322673149	510661	30/11/20

[5]:
```
dim(training_data)
dim(testing_data)
```

1. 19622 2. 160

1. 20 2. 160

1.8 Preprocessing

[6]:
```
nonZero <- nearZeroVar(training_data)

training_data <- training_data[, -nonZero]
testing_data <- testing_data[, -nonZero]
```

[7]:
```
dim(training_data)
```

1. 19622 2. 100

[8]:
```
nas <- sapply(training_data, function(x) mean(is.na(x))) > 0.95
```

[9]:
```
nas
```

X FALSE **user_name** FALSE **raw_timestamp_part_1** FALSE **raw_timestamp_part_2** FALSE **cvtd_timestamp** FALSE **num_window** FALSE **roll_belt** FALSE **pitch_belt** FALSE **yaw_belt** FALSE **total_accel_belt** FALSE **max_roll_belt** TRUE **max_picth_belt** TRUE **min_roll_belt** TRUE **min_pitch_belt** TRUE **amplitude_roll_belt** TRUE **amplitude_pitch_belt** TRUE **var_total_accel_belt** TRUE **avg_roll_belt** TRUE **stddev_roll_belt** TRUE **var_roll_belt** TRUE **avg_pitch_belt** TRUE **stddev_pitch_belt** TRUE **var_pitch_belt** TRUE **avg_yaw_belt** TRUE **stddev_yaw_belt** TRUE

var__yaw__belt TRUE gyros__belt__x FALSE gyros__belt__y FALSE
gyros__belt__z FALSE accel__belt__x FALSE accel__belt__y FALSE
accel__belt__z FALSE magnet__belt__x FALSE magnet__belt__y FALSE
magnet__belt__z FALSE roll__arm FALSE pitch__arm FALSE yaw__arm FALSE
total__accel__arm FALSE var__accel__arm TRUE gyros__arm__x FALSE
gyros__arm__y FALSE gyros__arm__z FALSE accel__arm__x FALSE
accel__arm__y FALSE accel__arm__z FALSE magnet__arm__x FALSE
magnet__arm__y FALSE magnet__arm__z FALSE max__picth__arm TRUE
max__yaw__arm TRUE min__yaw__arm TRUE amplitude__yaw__arm TRUE
roll__dumbbell FALSE pitch__dumbbell FALSE yaw__dumbbell FALSE
max__roll__dumbbell TRUE max__picth__dumbbell TRUE min__roll__dumbbell
TRUE min__pitch__dumbbell TRUE amplitude__roll__dumbbell TRUE
amplitude__pitch__dumbbell TRUE total__accel__dumbbell FALSE
var__accel__dumbbell TRUE avg__roll__dumbbell TRUE stddev__roll__dumbbell
TRUE var__roll__dumbbell TRUE avg__pitch__dumbbell TRUE
stddev__pitch__dumbbell TRUE var__pitch__dumbbell TRUE
avg__yaw__dumbbell TRUE stddev__yaw__dumbbell TRUE var__yaw__dumbbell
TRUE gyros__dumbbell__x FALSE gyros__dumbbell__y FALSE
gyros__dumbbell__z FALSE accel__dumbbell__x FALSE accel__dumbbell__y
FALSE accel__dumbbell__z FALSE magnet__dumbbell__x FALSE
magnet__dumbbell__y FALSE magnet__dumbbell__z FALSE roll__forearm FALSE
pitch__forearm FALSE yaw__forearm FALSE max__picth__forearm TRUE
min__pitch__forearm TRUE amplitude__pitch__forearm TRUE
total__accel__forearm FALSE var__accel__forearm TRUE gyros__forearm__x
FALSE gyros__forearm__y FALSE gyros__forearm__z FALSE accel__forearm__x
FALSE accel__forearm__y FALSE accel__forearm__z FALSE magnet__forearm__x
FALSE magnet__forearm__y FALSE magnet__forearm__z FALSE classe FALSE

[10]:
```
training_data <- training_data[,nas == FALSE]
testing_data <- testing_data[,nas == FALSE]
```

[11]:
```
dim(training_data)
```

1. 19622 2. 59

[12]:
```
summary(training_data)
```

```
       X          user_name         raw_timestamp_part_1 raw_timestamp_part_2
 Min.   :    1   Length:19622       Min.   :1.322e+09    Min.   :   294
 1st Qu.: 4906   Class :character   1st Qu.:1.323e+09    1st Qu.:252912
 Median : 9812   Mode  :character   Median :1.323e+09    Median :496380
 Mean   : 9812                      Mean   :1.323e+09    Mean   :500656
 3rd Qu.:14717                      3rd Qu.:1.323e+09    3rd Qu.:751891
 Max.   :19622                      Max.   :1.323e+09    Max.   :998801
 cvtd_timestamp       num_window      roll_belt        pitch_belt
 Length:19622       Min.   :  1.0   Min.   :-28.90   Min.   :-55.8000
 Class :character   1st Qu.:222.0   1st Qu.:  1.10   1st Qu.:  1.7600
 Mode  :character   Median :424.0   Median :113.00   Median :  5.2800
                    Mean   :430.6   Mean   : 64.41   Mean   :  0.3053
```

```
                 3rd Qu.:644.0   3rd Qu.:123.00   3rd Qu.: 14.9000
                 Max.   :864.0   Max.   :162.00   Max.   : 60.3000
   yaw_belt       total_accel_belt  gyros_belt_x        gyros_belt_y
Min.   :-180.00   Min.   : 0.00    Min.   :-1.040000   Min.   :-0.64000
1st Qu.: -88.30   1st Qu.: 3.00    1st Qu.:-0.030000   1st Qu.: 0.00000
Median : -13.00   Median :17.00    Median : 0.030000   Median : 0.02000
Mean   : -11.21   Mean   :11.31    Mean   :-0.005592   Mean   : 0.03959
3rd Qu.:  12.90   3rd Qu.:18.00    3rd Qu.: 0.110000   3rd Qu.: 0.11000
Max.   : 179.00   Max.   :29.00    Max.   : 2.220000   Max.   : 0.64000
 gyros_belt_z      accel_belt_x       accel_belt_y     accel_belt_z
Min.   :-1.4600   Min.   :-120.000   Min.   :-69.00   Min.   :-275.00
1st Qu.:-0.2000   1st Qu.: -21.000   1st Qu.:  3.00   1st Qu.:-162.00
Median :-0.1000   Median : -15.000   Median : 35.00   Median :-152.00
Mean   :-0.1305   Mean   :  -5.595   Mean   : 30.15   Mean   : -72.59
3rd Qu.:-0.0200   3rd Qu.:  -5.000   3rd Qu.: 61.00   3rd Qu.:  27.00
Max.   : 1.6200   Max.   :  85.000   Max.   :164.00   Max.   : 105.00
magnet_belt_x   magnet_belt_y   magnet_belt_z       roll_arm
Min.   :-52.0   Min.   :354.0   Min.   :-623.0   Min.   :-180.00
1st Qu.:  9.0   1st Qu.:581.0   1st Qu.:-375.0   1st Qu.: -31.77
Median : 35.0   Median :601.0   Median :-320.0   Median :   0.00
Mean   : 55.6   Mean   :593.7   Mean   :-345.5   Mean   :  17.83
3rd Qu.: 59.0   3rd Qu.:610.0   3rd Qu.:-306.0   3rd Qu.:  77.30
Max.   :485.0   Max.   :673.0   Max.   : 293.0   Max.   : 180.00
  pitch_arm          yaw_arm          total_accel_arm  gyros_arm_x
Min.   :-88.800   Min.   :-180.0000   Min.   : 1.00   Min.   :-6.37000
1st Qu.:-25.900   1st Qu.: -43.1000   1st Qu.:17.00   1st Qu.:-1.33000
Median :  0.000   Median :   0.0000   Median :27.00   Median : 0.08000
Mean   : -4.612   Mean   :  -0.6188   Mean   :25.51   Mean   : 0.04277
3rd Qu.: 11.200   3rd Qu.:  45.8750   3rd Qu.:33.00   3rd Qu.: 1.57000
Max.   : 88.500   Max.   : 180.0000   Max.   :66.00   Max.   : 4.87000
 gyros_arm_y       gyros_arm_z       accel_arm_x       accel_arm_y
Min.   :-3.4400   Min.   :-2.3300   Min.   :-404.00   Min.   :-318.0
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   Max.   : 3.0200   Max.   : 437.00   Max.   : 308.0
 accel_arm_z       magnet_arm_x     magnet_arm_y     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 : 202.0   Median : 444.0
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
roll_dumbbell     pitch_dumbbell     yaw_dumbbell      total_accel_dumbbell
Min.   :-153.71   Min.   :-149.59   Min.   :-150.871   Min.   : 0.00
1st Qu.: -18.49   1st Qu.: -40.89   1st Qu.: -77.644   1st Qu.: 4.00
Median :  48.17   Median : -20.96   Median :  -3.324   Median :10.00
```

```
Mean   :  23.84   Mean   : -10.78   Mean   :   1.674   Mean   :13.72
3rd Qu.:  67.61   3rd Qu.:  17.50   3rd Qu.:  79.643   3rd Qu.:19.00
Max.   : 153.55   Max.   : 149.40   Max.   : 154.952   Max.   :58.00
gyros_dumbbell_x    gyros_dumbbell_y   gyros_dumbbell_z  accel_dumbbell_x
Min.   :-204.0000   Min.   :-2.10000   Min.   : -2.380   Min.   :-419.00
1st Qu.:  -0.0300   1st Qu.:-0.14000   1st Qu.: -0.310   1st Qu.: -50.00
Median :   0.1300   Median : 0.03000   Median : -0.130   Median :  -8.00
Mean   :   0.1611   Mean   : 0.04606   Mean   : -0.129   Mean   : -28.62
3rd Qu.:   0.3500   3rd Qu.: 0.21000   3rd Qu.:  0.030   3rd Qu.:  11.00
Max.   :   2.2200   Max.   :52.00000   Max.   :317.000   Max.   : 235.00
accel_dumbbell_y  accel_dumbbell_z  magnet_dumbbell_x magnet_dumbbell_y
Min.   :-189.00   Min.   :-334.00   Min.   :-643.0    Min.   :-3600
1st Qu.:  -8.00   1st Qu.:-142.00   1st Qu.:-535.0    1st Qu.:  231
Median :  41.50   Median :  -1.00   Median :-479.0    Median :  311
Mean   :  52.63   Mean   : -38.32   Mean   :-328.5    Mean   :  221
3rd Qu.: 111.00   3rd Qu.:  38.00   3rd Qu.:-304.0    3rd Qu.:  390
Max.   : 315.00   Max.   : 318.00   Max.   : 592.0    Max.   :  633
magnet_dumbbell_z  roll_forearm       pitch_forearm     yaw_forearm
Min.   :-262.00   Min.   :-180.0000   Min.   :-72.50   Min.   :-180.00
1st Qu.: -45.00   1st Qu.:  -0.7375   1st Qu.:  0.00   1st Qu.: -68.60
Median :  13.00   Median :  21.7000   Median :  9.24   Median :   0.00
Mean   :  46.05   Mean   :  33.8265   Mean   : 10.71   Mean   :  19.21
3rd Qu.:  95.00   3rd Qu.: 140.0000   3rd Qu.: 28.40   3rd Qu.: 110.00
Max.   : 452.00   Max.   : 180.0000   Max.   : 89.80   Max.   : 180.00
total_accel_forearm gyros_forearm_x   gyros_forearm_y     gyros_forearm_z
Min.   :  0.00      Min.   :-22.000   Min.   : -7.02000   Min.   : -8.0900
1st Qu.: 29.00      1st Qu.: -0.220   1st Qu.: -1.46000   1st Qu.: -0.1800
Median : 36.00      Median :  0.050   Median :  0.03000   Median :  0.0800
Mean   : 34.72      Mean   :  0.158   Mean   :  0.07517   Mean   :  0.1512
3rd Qu.: 41.00      3rd Qu.:  0.560   3rd Qu.:  1.62000   3rd Qu.:  0.4900
Max.   :108.00      Max.   :  3.970   Max.   :311.00000   Max.   :231.0000
accel_forearm_x   accel_forearm_y  accel_forearm_z   magnet_forearm_x
Min.   :-498.00   Min.   :-632.0   Min.   :-446.00   Min.   :-1280.0
1st Qu.:-178.00   1st Qu.:  57.0   1st Qu.:-182.00   1st Qu.: -616.0
Median : -57.00   Median : 201.0   Median : -39.00   Median : -378.0
Mean   : -61.65   Mean   : 163.7   Mean   : -55.29   Mean   : -312.6
3rd Qu.:  76.00   3rd Qu.: 312.0   3rd Qu.:  26.00   3rd Qu.:  -73.0
Max.   : 477.00   Max.   : 923.0   Max.   : 291.00   Max.   :  672.0
magnet_forearm_y magnet_forearm_z    classe
Min.   :-896.0   Min.   :-973.0   Length:19622
1st Qu.:   2.0   1st Qu.: 191.0   Class :character
Median : 591.0   Median : 511.0   Mode  :character
Mean   : 380.1   Mean   : 393.6
3rd Qu.: 737.0   3rd Qu.: 653.0
Max.   :1480.0   Max.   :1090.0
```

[13]:
```
chars <- sapply(training_data, is.character)
```

[14]:
```
training_data <- subset(training_data, select = -c(X, user_name,␣
↪cvtd_timestamp))
```

1.8.1 Data Partitioning

[15]:
```
partition <- createDataPartition(training_data$classe, p=0.6, list=FALSE)
training_data <- training_data[partition,]
testing_data <- training_data[-partition,]

dim(training_data)
```

1. 11776 2. 56

[16]:
```
dim(testing_data)
```

1. 4710 2. 56

1.8.2 Models

[17]:
```
model <- train(classe ~ ., data = training_data, method="rpart")
```

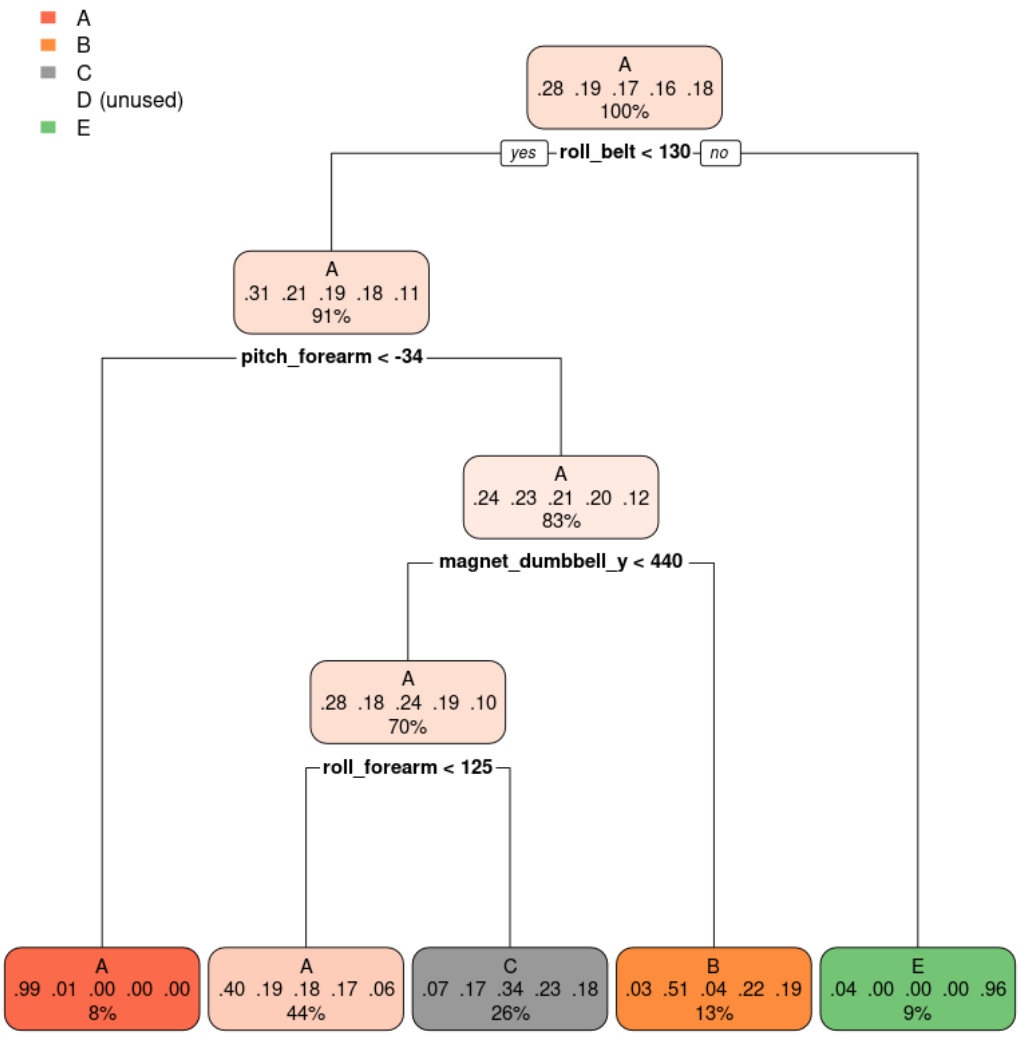
[18]:
```
pred <- predict(model, testing_data)
```

[20]:
```
confusionMatrix(pred, as.factor(testing_data$classe))
```

```
Confusion Matrix and Statistics

          Reference
Prediction    A    B    C    D    E
         A 1217  406  374  360  112
         B   15  308   24  126  123
         C   96  191  428  283  221
         D    0    0    0    0    0
         E   17    0    0    0  409

Overall Statistics

               Accuracy : 0.5015
                 95% CI : (0.4871, 0.5159)
    No Information Rate : 0.2856
    P-Value [Acc > NIR] : < 2.2e-16

                  Kappa : 0.3475

 Mcnemar's Test P-Value : NA

Statistics by Class:

                     Class: A Class: B Class: C Class: D Class: E
```

Sensitivity	0.9048	0.34033	0.51816	0.0000	0.47283
Specificity	0.6279	0.92431	0.79634	1.0000	0.99558
Pos Pred Value	0.4929	0.51678	0.35111	NaN	0.96009
Neg Pred Value	0.9429	0.85489	0.88599	0.8367	0.89356
Prevalence	0.2856	0.19214	0.17537	0.1633	0.18365
Detection Rate	0.2584	0.06539	0.09087	0.0000	0.08684
Detection Prevalence	0.5242	0.12654	0.25881	0.0000	0.09045
Balanced Accuracy	0.7664	0.63232	0.65725	0.5000	0.73421

[21]:
```
rpart.plot(model$finalModel, roundint = FALSE)
```



[22]:
```
model_2 <- train(classe ~ ., data = training_data, method = "rf", ntree = 50)
```

[29]:
```
pred1 <- predict(model_2, testing_data)
RF_CM <- confusionMatrix(pred1, as.factor(testing_data$classe))
RF_CM
```

```
Confusion Matrix and Statistics

          Reference
Prediction    A    B    C    D    E
         A 1345    0    0    0    0
         B    0  905    0    0    0
         C    0    0  826    0    0
         D    0    0    0  769    0
         E    0    0    0    0  865

Overall Statistics

               Accuracy : 1
                 95% CI : (0.9992, 1)
    No Information Rate : 0.2856
    P-Value [Acc > NIR] : < 2.2e-16

                  Kappa : 1

 Mcnemar's Test P-Value : NA

Statistics by Class:

                     Class: A Class: B Class: C Class: D Class: E
Sensitivity            1.0000   1.0000   1.0000   1.0000   1.0000
Specificity            1.0000   1.0000   1.0000   1.0000   1.0000
Pos Pred Value         1.0000   1.0000   1.0000   1.0000   1.0000
Neg Pred Value         1.0000   1.0000   1.0000   1.0000   1.0000
Prevalence             0.2856   0.1921   0.1754   0.1633   0.1837
Detection Rate         0.2856   0.1921   0.1754   0.1633   0.1837
Detection Prevalence   0.2856   0.1921   0.1754   0.1633   0.1837
Balanced Accuracy      1.0000   1.0000   1.0000   1.0000   1.0000
```

[27]:
```
model_3 <- train(classe ~ ., data = training_data, method = "gbm", verbose =␣
↪FALSE)
```

[30]:
```
pred2 <- predict(model_3, testing_data)
GBM_CM <- confusionMatrix(pred2, as.factor(testing_data$classe))
GBM_CM
```

```
Confusion Matrix and Statistics

          Reference
Prediction    A    B    C    D    E
```

```
          A 1345    0    0    0    0
          B    0  905    3    0    0
          C    0    0  821    3    0
          D    0    0    2  766    0
          E    0    0    0    0  865

Overall Statistics

               Accuracy : 0.9983
                 95% CI : (0.9967, 0.9993)
    No Information Rate : 0.2856
    P-Value [Acc > NIR] : < 2.2e-16

                  Kappa : 0.9979

 Mcnemar's Test P-Value : NA

Statistics by Class:

                     Class: A Class: B Class: C Class: D Class: E
Sensitivity            1.0000   1.0000   0.9939   0.9961   1.0000
Specificity            1.0000   0.9992   0.9992   0.9995   1.0000
Pos Pred Value         1.0000   0.9967   0.9964   0.9974   1.0000
Neg Pred Value         1.0000   1.0000   0.9987   0.9992   1.0000
Prevalence             0.2856   0.1921   0.1754   0.1633   0.1837
Detection Rate         0.2856   0.1921   0.1743   0.1626   0.1837
Detection Prevalence   0.2856   0.1928   0.1749   0.1631   0.1837
Balanced Accuracy      1.0000   0.9996   0.9966   0.9978   1.0000
```

[31]:
```
RF_CM$overall
```

Accuracy 1 **Kappa** 1 **AccuracyLower** 0.999217105039691 **AccuracyUpper** 1 **AccuracyNull** 0.285562632696391 **AccuracyPValue** 0 **McnemarPValue** NaN

[32]:
```
GBM_CM$overall
```

Accuracy 0.998301486199575 **Kappa** 0.997851019288699 **AccuracyLower** 0.996656008367532 **AccuracyUpper** 0.999266426056025 **AccuracyNull** 0.285562632696391 **AccuracyPValue** 0 **McnemarPValue** NaN

1.9 Conclusion

The Random Forest Model has a perfect accuracy of 1, so we will use this model for the final prediction

[33]:
```
final_pred <- read.csv('pml-testing.csv')
```

[34]:
```
predict(model_2, final_pred)
```

1. B 2. A 3. B 4. A 5. A 6. E 7. D 8. B 9. A 10. A 11. B 12. C 13. B 14. A 15. E 16. E 17. A 18. B 19. B 20. B

Levels: 1. 'A' 2. 'B' 3. 'C' 4. 'D' 5. 'E'