ml project

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Predicting Heart Disease

The `heart` dataset (source: UCI Machine Learning Repository) contains 920 observations and 76 variables. However, we're only using the following 14 of the 76 variables in our study:

- `age`: patient age (in years)
- `sex`: gender of patient; 0 = male, 1 = female
- `cp`: chest pain type; 1 = typical angina, 2 = atypical angina, 3 = non-anginal pain, 4 = asymptomatic
- `trestbps`: resting blood pressure (in mmHg)
- `chol`: serum cholesterol (in mg/dl)
- `fbs`: fasting blood sugar > 120 mg/dl; 0 = false, 1 = true
- `restecg`: resting electrocardiographic results; 0 = normal, 1 = having ST-T wave abnormality, 2 = showing probable or definite left ventricular hypertrophy by Ester's criteria
- `thalach`: maximum heart race achieved
- `exang`: exercise included angina; 0 = no, 1 = yes
- `oldpeak`: ST depression induced by exercise relative to rest
- `slope`: the slope of the peak exercise ST segment; 1 = upsloping, 2 = flat, 3 = downsloping
- `ca`: number of major vessels (0-3) colored by fluoroscopy
- `thal`: thalassemia; 3 = normal, 6 = fixed defect, 7 = reversible defect
- `num`: diagosis of heart disease; 0 = no heart disease, 1 = have heart disease

Load, Merge, and Recode Data

```
library(dplyr)
```

```
##
## Attaching package: 'dplyr'

## The following objects are masked from 'package:stats':
##
##     filter, lag

## The following objects are masked from 'package:base':
##
##     intersect, setdiff, setequal, union
```

```
cleveland <- read.csv("/Users/jiayizhao/Desktop/2338 Machine Learning/heart_disease_final_data/processe
hungarian <- read.csv("/Users/jiayizhao/Desktop/2338 Machine Learning/heart_disease_final_data/processe
switzerland <- read.csv("/Users/jiayizhao/Desktop/2338 Machine Learning/heart_disease_final_data/process
va <- read.csv("/Users/jiayizhao/Desktop/2338 Machine Learning/heart_disease_final_data/processed.va.cs
```

```r
nrow(cleveland)
```

```
## [1] 303
```

```r
nrow(hungarian)
```

```
## [1] 294
```

```r
nrow(switzerland)
```

```
## [1] 123
```

```r
nrow(va)
```

```
## [1] 200
```

```r
heart <- rbind(cleveland, hungarian, switzerland, va)

# check for missing values
heart[heart == "?"] <- NA
sum(is.na(heart))
```

```
## [1] 1759
```

```r
sapply(heart, function(x) sum(is.na(x)))
```

```
##      age      sex       cp trestbps     chol      fbs  restecg  thalach 
##        0        0        0       59       30       90        2       55 
##    exang  oldpeak    slope       ca     thal      num 
##       55       62      309      611      486        0 
```

```r
nrow(heart)
```

```
## [1] 920
```

```r
ncol(heart)
```

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

Univariable Analysis

```r
library(dplyr)
heart$age <- as.numeric(heart$age)
heart$trestbps <- as.numeric(heart$trestbps)
heart$chol <- as.numeric(heart$chol)
heart$thalach <- as.numeric(heart$thalach)
heart$oldpeak <- as.numeric(heart$oldpeak)
heart <- na.omit(heart)
#Univariate Analysis on Continuous Data
summary(heart)
```

```
##       age             sex               cp           trestbps    
##  Min.   :29.00   Min.   :0.0000   Min.   :1.000   Min.   : 94.0  
##  1st Qu.:48.00   1st Qu.:0.0000   1st Qu.:3.000   1st Qu.:120.0  
##  Median :56.00   Median :1.0000   Median :3.000   Median :130.0  
##  Mean   :54.52   Mean   :0.6789   Mean   :3.164   Mean   :131.7  
##  3rd Qu.:61.00   3rd Qu.:1.0000   3rd Qu.:4.000   3rd Qu.:140.0  
##  Max.   :77.00   Max.   :1.0000   Max.   :4.000   Max.   :200.0  
##       chol            fbs              restecg             thalach     
##  Min.   :100.0   Length:299         Length:299         Min.   : 71.0  
##  1st Qu.:211.0   Class :character   Class :character   1st Qu.:132.5  
##  Median :242.0   Mode  :character   Mode  :character   Median :152.0  
##  Mean   :246.8                                         Mean   :149.3  
##  3rd Qu.:275.5                                         3rd Qu.:165.5  
##  Max.   :564.0                                         Max.   :202.0  
##     exang              oldpeak         slope                ca           
##  Length:299         Min.   :0.000   Length:299         Length:299        
##  Class :character   1st Qu.:0.000   Class :character   Class :character  
##  Mode  :character   Median :0.800   Mode  :character   Mode  :character  
##                     Mean   :1.059                                        
##                     3rd Qu.:1.600                                        
##                     Max.   :6.200                                        
##      thal                num        
##  Length:299         Min.   :0.0000  
##  Class :character   1st Qu.:0.0000  
##  Mode  :character   Median :0.0000  
##                     Mean   :0.9465  
##                     3rd Qu.:2.0000  
##                     Max.   :4.0000
```

```
sd_values <- sapply(heart[, c("age", "trestbps", "chol", "thalach", "oldpeak")], sd)
print(sd_values)
```

```
##       age  trestbps      chol   thalach   oldpeak 
##  9.030264 17.747751 52.532582 23.121062  1.162769
```

```
#Univariate Analysis on Categorical Data
sex_counts <- table(heart$sex)
sex_percentages <- prop.table(sex_counts) * 100
sex_summary <- data.frame(sex = names(sex_counts),
                             Count = as.numeric(sex_counts),
                             Percentage = sex_percentages)
print(sex_summary)
```

```
##   sex Count Percentage.Var1 Percentage.Freq
## 1   0    96               0        32.10702
## 2   1   203               1        67.89298
```

```
cp_counts <- table(heart$cp)
cp_percentages <- prop.table(cp_counts) * 100
cp_summary <- data.frame(cp = names(cp_counts),
                             Count = as.numeric(cp_counts),
                             Percentage = cp_percentages)
print(cp_summary)
```

```
##   cp Count Percentage.Var1 Percentage.Freq
## 1  1    23               1         7.692308
## 2  2    49               2        16.387960
## 3  3    83               3        27.759197
## 4  4   144               4        48.160535
```

```
fbs_counts <- table(heart$fbs)
fbs_percentages <- prop.table(fbs_counts) * 100
fbs_summary <- data.frame(fbs = names(fbs_counts),
                             Count = as.numeric(fbs_counts),
                             Percentage = fbs_percentages)
print(fbs_summary)
```

```
##   fbs Count Percentage.Var1 Percentage.Freq
## 1   0   256               0        85.61873
## 2   1    43               1        14.38127
```

```
restecg_counts <- table(heart$restecg)
restecg_percentages <- prop.table(restecg_counts) * 100
restecg_summary <- data.frame(restecg = names(restecg_counts),
                             Count = as.numeric(restecg_counts),
                             Percentage = restecg_percentages)
print(restecg_summary)
```

```
##   restecg Count Percentage.Var1 Percentage.Freq
## 1       0   149               0       49.832776
## 2       1     4               1        1.337793
## 3       2   146               2       48.829431
```

```
exang_counts <- table(heart$exang)
exang_percentages <- prop.table(exang_counts) * 100
exang_summary <- data.frame(exang = names(exang_counts),
                             Count = as.numeric(exang_counts),
                             Percentage = exang_percentages)
print(exang_summary)
```

```
##   exang Count Percentage.Var1 Percentage.Freq
## 1     0   200               0        66.88963
## 2     1    99               1        33.11037
```

```
slope_counts <- table(heart$slope)
slope_percentages <- prop.table(slope_counts) * 100
slope_summary <- data.frame(slope = names(slope_counts),
                             Count = as.numeric(slope_counts),
                             Percentage = slope_percentages)
print(slope_summary)
```

```
##   slope Count Percentage.Var1 Percentage.Freq
## 1     1   139               1       46.488294
## 2     2   139               2       46.488294
## 3     3    21               3        7.023411
```

```
ca_counts <- table(heart$ca)
ca_percentages <- prop.table(ca_counts) * 100
ca_summary <- data.frame(ca = names(ca_counts),
                             Count = as.numeric(ca_counts),
                             Percentage = ca_percentages)
print(ca_summary)
```

```
##   ca Count Percentage.Var1 Percentage.Freq
## 1  0   176               0       58.862876
## 2  1    65               1       21.739130
## 3  2    38               2       12.709030
## 4  3    20               3        6.688963
```

```
thal_counts <- table(heart$thal)
thal_percentages <- prop.table(thal_counts) * 100
```

```
thal_summary <- data.frame(thal = names(thal_counts),
                           Count = as.numeric(thal_counts),
                           Percentage = thal_percentages)
print(thal_summary)
```

```
##   thal Count Percentage.Var1 Percentage.Freq
## 1    3   164               3       54.849498
## 2    6    18               6        6.020067
## 3    7   117               7       39.130435
```

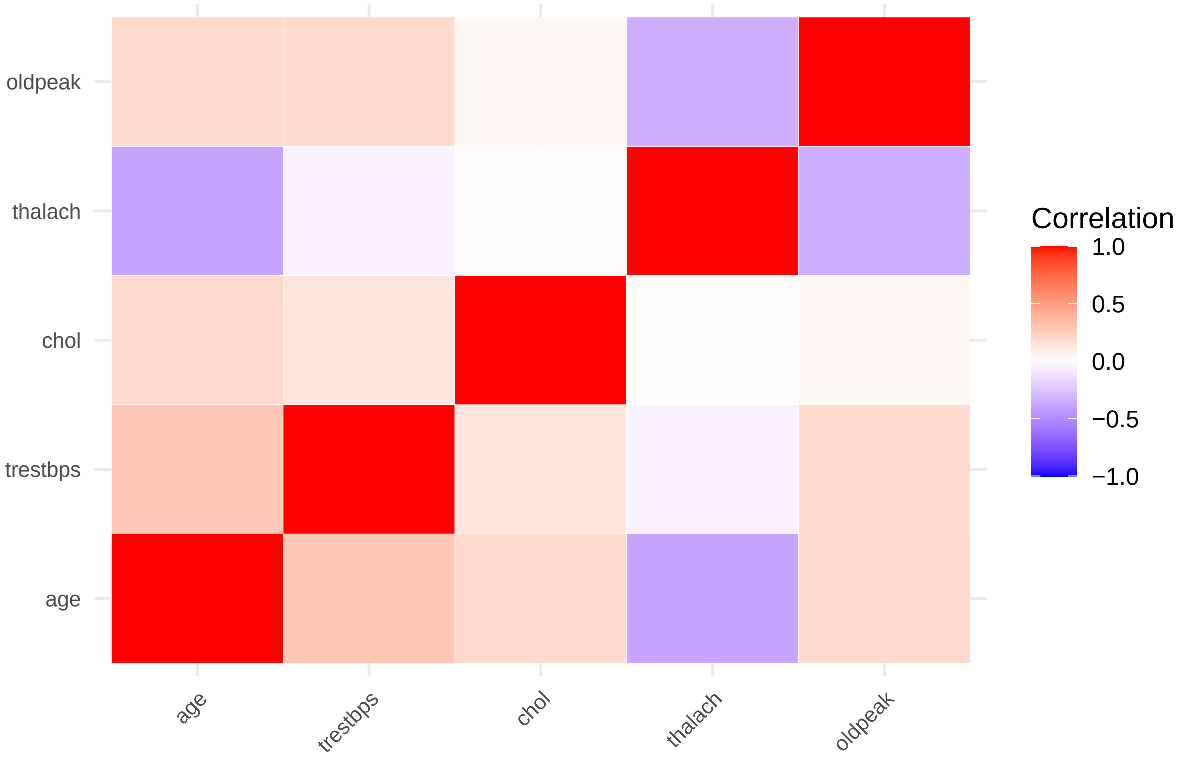
```
num_counts <- table(heart$num)
num_percentages <- prop.table(num_counts) * 100
num_summary <- data.frame(num = names(num_counts),
                           Count = as.numeric(num_counts),
                           Percentage = num_percentages)
print(num_summary)
```

```
##   num Count Percentage.Var1 Percentage.Freq
## 1   0   160               0       53.511706
## 2   1    56               1       18.729097
## 3   2    35               2       11.705686
## 4   3    35               3       11.705686
## 5   4    13               4        4.347826
```

Correlation Heatmap

```
library(reshape2)
cor_matrix <- cor(heart[, c("age", "trestbps", "chol", "thalach", "oldpeak")])
melted_cor_matrix <- melt(cor_matrix)

library(ggplot2)
ggplot(melted_cor_matrix, aes(Var1, Var2, fill = value)) +
  geom_tile(color = "white") +
  scale_fill_gradient2(low = "blue", high = "red", mid = "white", midpoint = 0, limit = c(-1,1), space =
  theme_minimal() +
  theme(
    axis.text.x = element_text(angle = 45, vjust = 1, size = 8, hjust = 1),
    axis.text.y = element_text(size = 8)
  ) +
  labs(x = "", y = "", title = "")
```



#Bar Chart

Deal with NA's

```
#convert integers to numeric, standardization and replace na with median
heart$age <- as.numeric(heart$age)
heart$age <- scale(heart$age)
heart$age[is.na(heart$age)] <- median(heart$age, na.rm = TRUE)

heart$trestbps <- as.numeric(heart$trestbps)
heart$trestbps <- scale(heart$trestbps)
heart$trestbps[is.na(heart$trestbps)] <- median(heart$trestbps, na.rm = TRUE)

heart$chol <- as.numeric(heart$chol)
heart$chol <- scale(heart$chol)
heart$chol[is.na(heart$chol)] <- median(heart$chol, na.rm = TRUE)

heart$thalach <- as.numeric(heart$thalach)
heart$thalach <- scale(heart$thalach)
heart$thalach[is.na(heart$thalach)] <- median(heart$thalach, na.rm = TRUE)

heart$oldpeak <- as.numeric(heart$oldpeak)
heart$oldpeak <- scale(heart$oldpeak)
heart$oldpeak[is.na(heart$oldpeak)] <- median(heart$oldpeak, na.rm = TRUE)

#replace NA values in the character variables into mode
heart$fbs <- ifelse(is.na(heart$fbs), names(which.max(table(heart$fbs))), heart$fbs)

heart$restecg <- ifelse(is.na(heart$restecg), names(which.max(table(heart$restecg))), heart$restecg)
```

```
heart$exang <- ifelse(is.na(heart$exang), names(which.max(table(heart$exang))), heart$exang)

heart$slope <- ifelse(is.na(heart$slope), names(which.max(table(heart$slope))), heart$slope)

#remove ca & thal, as more than half of their observations are mising values.
heart$ca <- NULL
heart$thal <- NULL

#check for missing values
sum(is.na(heart))
```

```
## [1] 0
```

```
sapply(heart, function(x) sum(is.na(x)))
```

```
##      age      sex       cp trestbps     chol      fbs  restecg  thalach 
##        0        0        0        0        0        0        0        0 
##    exang  oldpeak    slope      num 
##        0        0        0        0
```

```
#convert character variables into factors
heart$sex <- factor(heart$sex,
                    levels = c(0, 1),
                    labels = c("male", "female"))

heart$cp <- factor(heart$cp,
                    levels = c(1, 2, 3, 4),
                    labels = c("typical angina", "atypial angina", "non-anginal pain", "asymptomatic"))

heart$fbs <- factor(heart$fbs,
                    levels = c(0, 1),
                    labels = c("false", "true"))

heart$restecg <- factor(heart$restecg,
                    levels = c(0, 1, 2),
                    labels = c("normal", "abonormal", "left ventricular hypertrophy"))

heart$exang <- factor(heart$exang,
                    levels = c(0, 1),
                    labels = c("no", "yes"))

heart$slope <- factor(heart$slope,
                    levels = c(1, 2, 3),
                    labels = c("upsloping", "flat", "downsloping"))

heart$num <- as.integer(heart$num > 0)
heart$num <- factor(heart$num,
                    levels = c(0, 1),
                    labels = c("no", "yes"))
```

Initial Data Preparation

```
library(tidyverse)
```

```
## -- Attaching core tidyverse packages ------------------------ tidyverse 2.0.0 --
## v forcats   1.0.0     v stringr   1.5.0
## v lubridate 1.9.3     v tibble    3.2.1
## v purrr     1.0.2     v tidyr     1.3.1
## v readr     2.1.4
## -- Conflicts ------------------------------------------ tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
## i Use the conflicted package (<http://conflicted.r-lib.org/>) to force all conflicts to become errors
```

```
library(caret)
```

```
## Loading required package: lattice
##
## Attaching package: 'caret'
##
## The following object is masked from 'package:purrr':
##
##     lift
```

```
set.seed(123)

tr_ind <- sample(1:nrow(heart), 0.8 * nrow(heart))
heart_train <- heart[tr_ind, ]
heart_test <- heart[-tr_ind, ]
```

Random Forest & Gradient Boosting

```
# Random Forest
library(randomForest)
```

```
## randomForest 4.7-1.1
```

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

```
##
## Attaching package: 'randomForest'
```

```
## The following object is masked from 'package:ggplot2':
##
##     margin
```

```
## The following object is masked from 'package:dplyr':
##
##     combine
```

```
library(e1071)
library(caret)

set.seed(123)
rf.hd <- randomForest(num ~., data =heart_train,importance=TRUE)
rf.hd
```

```
##
## Call:
##  randomForest(formula = num ~ ., data = heart_train, importance = TRUE)
##                Type of random forest: classification
##                      Number of trees: 500
## No. of variables tried at each split: 3
##
##         OOB estimate of  error rate: 24.69%
## Confusion matrix:
##      no yes class.error
## no  106  25   0.1908397
## yes  34  74   0.3148148
```

```r
# Split the test dataset into predictors (X_test) and outcome (y_test)
X_test <- heart_test[, -which(names(heart_test) == "num")]  # Exclude the outcome variable
y_test <- heart_test$num
# Make predictions
predictions <- predict(rf.hd, X_test)
# Evaluate the model
confusion_matrix <- confusionMatrix(predictions,
                                    y_test,
                                    mode = "everything")
print(confusion_matrix)
```

```
## Confusion Matrix and Statistics
##
##           Reference
## Prediction no yes
##        no  27   8
##        yes  2  23
##
##                Accuracy : 0.8333
##                  95% CI : (0.7148, 0.9171)
##     No Information Rate : 0.5167
##     P-Value [Acc > NIR] : 3.014e-07
##
##                   Kappa : 0.6685
##
##  Mcnemar's Test P-Value : 0.1138
##
##             Sensitivity : 0.9310
##             Specificity : 0.7419
##          Pos Pred Value : 0.7714
##          Neg Pred Value : 0.9200
##               Precision : 0.7714
##                  Recall : 0.9310
##                      F1 : 0.8438
##              Prevalence : 0.4833
##          Detection Rate : 0.4500
##    Detection Prevalence : 0.5833
##       Balanced Accuracy : 0.8365
##
##        'Positive' Class : no
##
```

```r
# Accuracy = 0.788
# F1 = 0.7153

# Training Error = 0.1997283
```

```
predict.train <- predict(rf.hd, new_data = heart_train,type= "response")
mean(predict.train != heart_train$num)
```

```
## [1] 0.2468619
```

```
# Testing Error = 0.2119565
predict.test <- predict(rf.hd,newdata = heart_test)
mean(predict.test != heart_test$num)
```

```
## [1] 0.1666667
```

```
# AUCROC
library(pROC)
```

```
## Type 'citation("pROC")' for a citation.
```

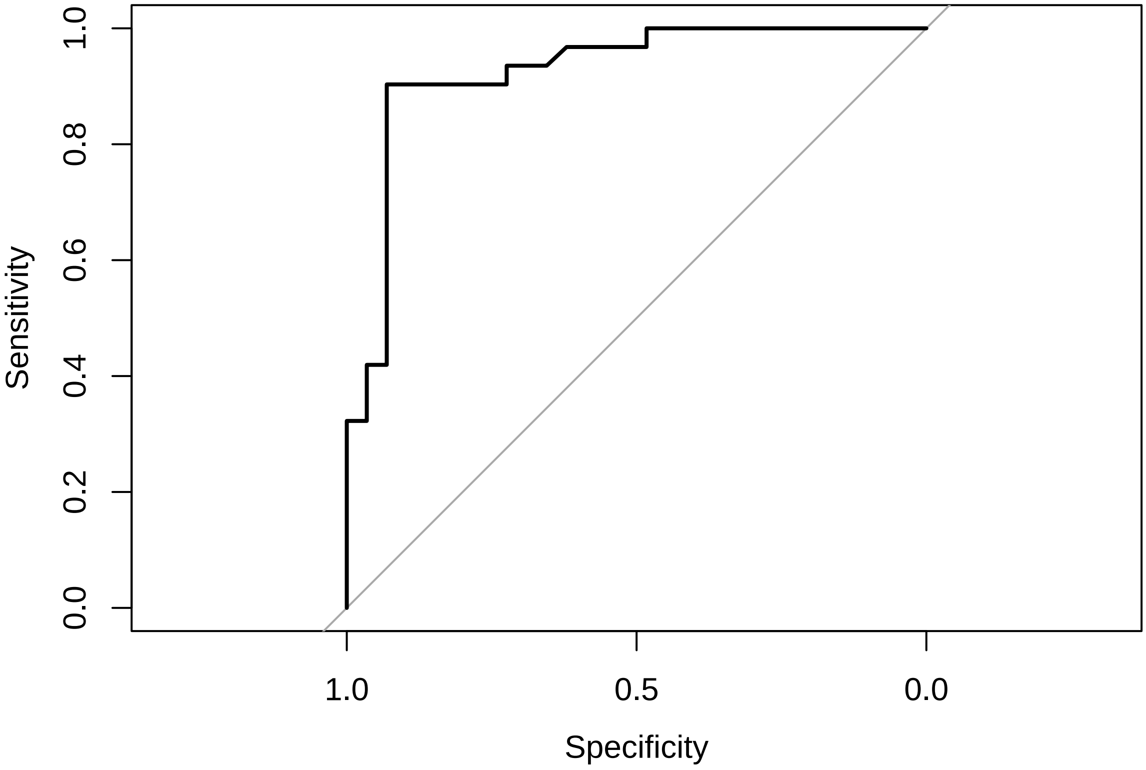
```
##
## Attaching package: 'pROC'
```

```
## The following objects are masked from 'package:stats':
##
##     cov, smooth, var
```

```
predictions.prob <- predict(rf.hd, X_test, type = "prob")
roc.rf <- roc(response = y_test, predictor = predictions.prob[,2], plot = TRUE)
```

```
## Setting levels: control = no, case = yes
```

```
## Setting direction: controls < cases
```



```
print(auc(roc.rf))
```

```
## Area under the curve: 0.926
```

```
# auc = 0.8754
```

```
#K-fold cross-validation
library(caret)
ctrl <- trainControl(method = "cv", number = 5, search = "grid")
tune_grid <- expand.grid(mtry = c(2, 4, 6, 8))

# Train the Random Forest model
rf_tuned <- train(num ~ .,
                  data = heart_train,       # Training dataset
                  method = "rf",            # Method for Random Forest
                  metric = "Accuracy",      # Metric to optimize
                  trControl = ctrl,         # Training control setup
                  tuneGrid = tune_grid)     # Grid of hyperparameters
rf_tuned
```

```
## Random Forest
##
## 239 samples
##  11 predictor
##   2 classes: 'no', 'yes'
##
## No pre-processing
## Resampling: Cross-Validated (5 fold)
## Summary of sample sizes: 192, 191, 191, 191, 191
## Resampling results across tuning parameters:
##
##   mtry  Accuracy   Kappa
##   2     0.7533688  0.4993379
##   4     0.7324468  0.4580624
##   6     0.7449468  0.4847485
##   8     0.7491135  0.4927044
##
## Accuracy was used to select the optimal model using the largest value.
## The final value used for the model was mtry = 2.
```

```
#The final value used for the model was mtry = 2.

# Make predictions on the test set using the tuned model
predictions_tuned <- predict(rf_tuned, X_test)

# Evaluate the tuned model
confusion_matrix_tuned <- confusionMatrix(predictions_tuned, y_test,,
                                    mode = "everything")
print(confusion_matrix_tuned)
```

```
## Confusion Matrix and Statistics
##
##           Reference
## Prediction no yes
##        no  27   6
##        yes  2  25
##
##                 Accuracy : 0.8667
##                   95% CI : (0.7541, 0.9406)
##     No Information Rate : 0.5167
##     P-Value [Acc > NIR] : 1.105e-08
##
##                   Kappa : 0.7342
##
##  Mcnemar's Test P-Value : 0.2888
##
##             Sensitivity : 0.9310
##             Specificity : 0.8065
##          Pos Pred Value : 0.8182
##          Neg Pred Value : 0.9259
##               Precision : 0.8182
##                  Recall : 0.9310
##                      F1 : 0.8710
##              Prevalence : 0.4833
##          Detection Rate : 0.4500
##    Detection Prevalence : 0.5500
##       Balanced Accuracy : 0.8687
##
##        'Positive' Class : no
##
```

```
#Accuracy = 0.8207
#F1 = 0.7660

# Training Error = 0.0611413
predict.train <- predict(rf_tuned, newdata = heart_train)
mean(predict.train != heart_train$num)
```

```
## [1] 0.008368201
```

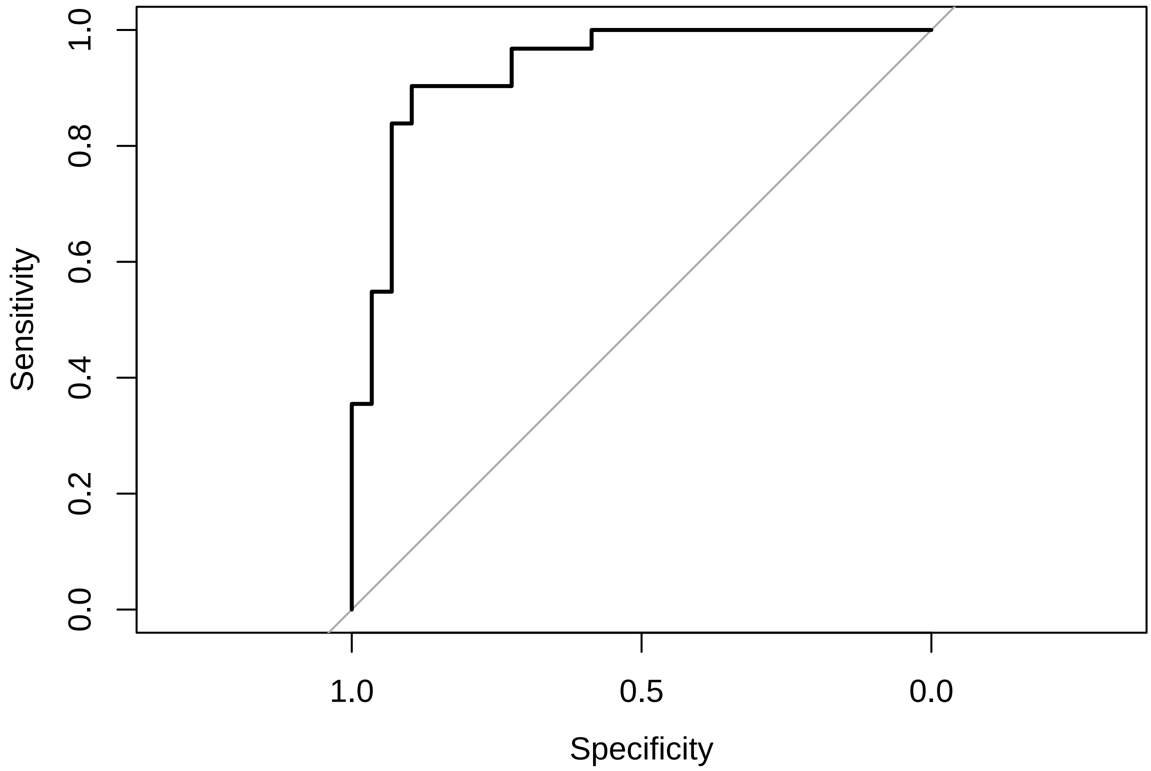
```
# Testing Error = 0.1793478
predict.test <- predict(rf_tuned,newdata = heart_test)
mean(predict.test != heart_test$num)
```

```
## [1] 0.1333333
```

```
# AUCROC
predictions.prob <- predict(rf_tuned, X_test, type = "prob")
roc.tuned.rf <- roc(response = y_test, predictor = predictions.prob[,2], plot = TRUE)
```

```
## Setting levels: control = no, case = yes
```

```
## Setting direction: controls < cases
```



```
print(auc(roc.tuned.rf))
```

```
## Area under the curve: 0.9355
```

```
# auc = 0.8963
```

```
## Loaded gbm 2.1.9
```

```
## This version of gbm is no longer under development. Consider transitioning to gbm3, https://github.c
```

```
## [1] yes no
## Levels: no yes
```

```
## [1] yes no
## Levels: no yes
```

```
## [1] 0.07112971
```

```
## [1] 0.1333333
```

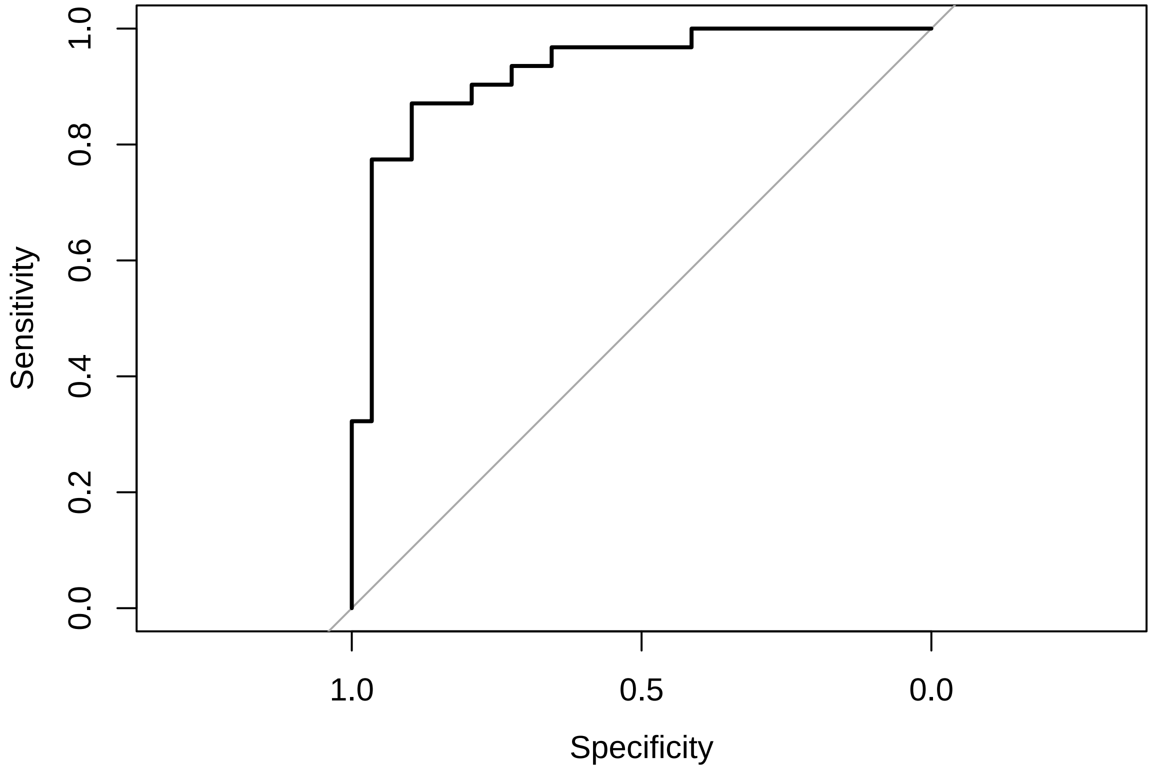
```
## Confusion Matrix and Statistics
##
##           Reference
## Prediction no yes
##        no  26   5
##        yes  3  26
##
##                Accuracy : 0.8667
##                  95% CI : (0.7541, 0.9406)
##     No Information Rate : 0.5167
##     P-Value [Acc > NIR] : 1.105e-08
##
##                   Kappa : 0.7336
```

```
##
##  Mcnemar's Test P-Value : 0.7237
##
##             Sensitivity : 0.8966
##             Specificity : 0.8387
##          Pos Pred Value : 0.8387
##          Neg Pred Value : 0.8966
##               Precision : 0.8387
##                  Recall : 0.8966
##                      F1 : 0.8667
##              Prevalence : 0.4833
##          Detection Rate : 0.4333
##    Detection Prevalence : 0.5167
##       Balanced Accuracy : 0.8676
##
##        'Positive' Class : no
##
```

```
## Using 60 trees...
```

```
## Setting levels: control = no, case = yes
```

```
## Setting direction: controls < cases
```



```
## Area under the curve: 0.9288
```

```
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3723             nan     0.0100    0.0015
##      2        1.3667             nan     0.0100    0.0021
##      3        1.3612             nan     0.0100    0.0019
##      4        1.3569             nan     0.0100    0.0020
##      5        1.3532             nan     0.0100    0.0014
##      6        1.3486             nan     0.0100    0.0020
##      7        1.3451             nan     0.0100    0.0011
##      8        1.3413             nan     0.0100    0.0020
##      9        1.3367             nan     0.0100    0.0016
##     10        1.3328             nan     0.0100    0.0019
##     20        1.2938             nan     0.0100    0.0017
##     40        1.2315             nan     0.0100    0.0008
##     60        1.1824             nan     0.0100    0.0011
##     80        1.1410             nan     0.0100    0.0002
##    100        1.1044             nan     0.0100    0.0007
##    120        1.0736             nan     0.0100    0.0004
##    140        1.0482             nan     0.0100    0.0004
##    150        1.0375             nan     0.0100    0.0002
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3731             nan     0.0100    0.0017
##      2        1.3685             nan     0.0100    0.0014
##      3        1.3633             nan     0.0100    0.0022
##      4        1.3594             nan     0.0100    0.0015
##      5        1.3553             nan     0.0100    0.0012
##      6        1.3514             nan     0.0100    0.0012
##      7        1.3475             nan     0.0100    0.0021
##      8        1.3440             nan     0.0100    0.0015
##      9        1.3406             nan     0.0100    0.0011
##     10        1.3366             nan     0.0100    0.0021
##     20        1.3013             nan     0.0100    0.0020
##     40        1.2381             nan     0.0100    0.0014
##     60        1.1852             nan     0.0100    0.0008
##     80        1.1433             nan     0.0100    0.0006
##    100        1.1080             nan     0.0100    0.0006
##    120        1.0795             nan     0.0100    0.0003
##    140        1.0529             nan     0.0100    0.0002
##    150        1.0415             nan     0.0100    0.0005
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3731             nan     0.0100    0.0018
##      2        1.3681             nan     0.0100    0.0015
##      3        1.3637             nan     0.0100    0.0022
##      4        1.3587             nan     0.0100    0.0021
##      5        1.3548             nan     0.0100    0.0010
##      6        1.3511             nan     0.0100    0.0016
##      7        1.3463             nan     0.0100    0.0021
##      8        1.3430             nan     0.0100    0.0009
##      9        1.3375             nan     0.0100    0.0018
##     10        1.3323             nan     0.0100    0.0017
##     20        1.2941             nan     0.0100    0.0013
##     40        1.2351             nan     0.0100    0.0008
##     60        1.1842             nan     0.0100    0.0005
##     80        1.1409             nan     0.0100    0.0006
##    100        1.1030             nan     0.0100    0.0007
##    120        1.0734             nan     0.0100    0.0004
##    140        1.0504             nan     0.0100    0.0003
##    150        1.0398             nan     0.0100    0.0003
##
```

```
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3701             nan     0.0100    0.0023
##      2        1.3619             nan     0.0100    0.0037
##      3        1.3550             nan     0.0100    0.0022
##      4        1.3478             nan     0.0100    0.0032
##      5        1.3410             nan     0.0100    0.0029
##      6        1.3370             nan     0.0100    0.0012
##      7        1.3319             nan     0.0100    0.0019
##      8        1.3251             nan     0.0100    0.0028
##      9        1.3180             nan     0.0100    0.0026
##     10        1.3139             nan     0.0100    0.0006
##     20        1.2607             nan     0.0100    0.0006
##     40        1.1646             nan     0.0100    0.0013
##     60        1.0902             nan     0.0100    0.0011
##     80        1.0329             nan     0.0100    0.0009
##    100        0.9869             nan     0.0100    0.0002
##    120        0.9455             nan     0.0100   -0.0003
##    140        0.9124             nan     0.0100    0.0004
##    150        0.8967             nan     0.0100    0.0005
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3711             nan     0.0100    0.0020
##      2        1.3637             nan     0.0100    0.0032
##      3        1.3570             nan     0.0100    0.0018
##      4        1.3500             nan     0.0100    0.0033
##      5        1.3426             nan     0.0100    0.0031
##      6        1.3355             nan     0.0100    0.0031
##      7        1.3281             nan     0.0100    0.0028
##      8        1.3226             nan     0.0100    0.0025
##      9        1.3154             nan     0.0100    0.0035
##     10        1.3085             nan     0.0100    0.0023
##     20        1.2537             nan     0.0100    0.0016
##     40        1.1627             nan     0.0100    0.0010
##     60        1.0911             nan     0.0100    0.0013
##     80        1.0360             nan     0.0100    0.0009
##    100        0.9898             nan     0.0100    0.0006
##    120        0.9553             nan     0.0100    0.0003
##    140        0.9242             nan     0.0100   -0.0002
##    150        0.9086             nan     0.0100   -0.0001
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3714             nan     0.0100    0.0022
##      2        1.3654             nan     0.0100    0.0025
##      3        1.3593             nan     0.0100    0.0023
##      4        1.3527             nan     0.0100    0.0027
##      5        1.3457             nan     0.0100    0.0033
##      6        1.3391             nan     0.0100    0.0030
##      7        1.3319             nan     0.0100    0.0033
##      8        1.3267             nan     0.0100    0.0025
##      9        1.3220             nan     0.0100    0.0012
##     10        1.3175             nan     0.0100    0.0017
##     20        1.2651             nan     0.0100    0.0025
##     40        1.1738             nan     0.0100    0.0018
##     60        1.1064             nan     0.0100    0.0006
##     80        1.0545             nan     0.0100    0.0006
##    100        1.0094             nan     0.0100    0.0007
##    120        0.9700             nan     0.0100   -0.0001
##    140        0.9382             nan     0.0100   -0.0001
##    150        0.9248             nan     0.0100   -0.0000
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3697             nan     0.0100    0.0030
##      2        1.3621             nan     0.0100    0.0027
##      3        1.3543             nan     0.0100    0.0027
##      4        1.3462             nan     0.0100    0.0019
##      5        1.3396             nan     0.0100    0.0022
##      6        1.3314             nan     0.0100    0.0030
##      7        1.3229             nan     0.0100    0.0031
##      8        1.3149             nan     0.0100    0.0027
##      9        1.3080             nan     0.0100    0.0025
##     10        1.3000             nan     0.0100    0.0030
##     20        1.2367             nan     0.0100    0.0012
##     40        1.1275             nan     0.0100    0.0009
##     60        1.0432             nan     0.0100    0.0003
##     80        0.9803             nan     0.0100    0.0003
##    100        0.9211             nan     0.0100    0.0009
##    120        0.8741             nan     0.0100   -0.0002
##    140        0.8355             nan     0.0100    0.0001
##    150        0.8166             nan     0.0100    0.0005
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3699             nan     0.0100    0.0025
##      2        1.3615             nan     0.0100    0.0036
##      3        1.3536             nan     0.0100    0.0028
##      4        1.3474             nan     0.0100    0.0016
##      5        1.3390             nan     0.0100    0.0036
##      6        1.3320             nan     0.0100    0.0027
##      7        1.3239             nan     0.0100    0.0029
##      8        1.3160             nan     0.0100    0.0030
##      9        1.3100             nan     0.0100    0.0022
##     10        1.3022             nan     0.0100    0.0033
##     20        1.2438             nan     0.0100    0.0026
##     40        1.1468             nan     0.0100    0.0018
##     60        1.0689             nan     0.0100    0.0014
##     80        1.0045             nan     0.0100    0.0007
##    100        0.9497             nan     0.0100    0.0001
##    120        0.9061             nan     0.0100    0.0003
##    140        0.8686             nan     0.0100   -0.0004
##    150        0.8521             nan     0.0100    0.0000
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3701             nan     0.0100    0.0034
##      2        1.3628             nan     0.0100    0.0026
##      3        1.3558             nan     0.0100    0.0019
##      4        1.3497             nan     0.0100    0.0028
##      5        1.3447             nan     0.0100    0.0016
##      6        1.3383             nan     0.0100    0.0025
##      7        1.3312             nan     0.0100    0.0034
##      8        1.3259             nan     0.0100    0.0013
##      9        1.3201             nan     0.0100    0.0022
##     10        1.3134             nan     0.0100    0.0031
##     20        1.2580             nan     0.0100    0.0015
##     40        1.1698             nan     0.0100    0.0021
##     60        1.0943             nan     0.0100    0.0014
##     80        1.0388             nan     0.0100    0.0011
##    100        0.9924             nan     0.0100    0.0007
##    120        0.9534             nan     0.0100    0.0001
##    140        0.9227             nan     0.0100   -0.0001
##    150        0.9072             nan     0.0100    0.0001
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3709             nan     0.0100    0.0027
##      2        1.3649             nan     0.0100    0.0026
##      3        1.3599             nan     0.0100    0.0017
##      4        1.3562             nan     0.0100    0.0014
##      5        1.3518             nan     0.0100    0.0017
##      6        1.3475             nan     0.0100    0.0015
##      7        1.3416             nan     0.0100    0.0025
##      8        1.3378             nan     0.0100    0.0014
##      9        1.3333             nan     0.0100    0.0024
##     10        1.3283             nan     0.0100    0.0025
##     20        1.2856             nan     0.0100    0.0019
##     40        1.2103             nan     0.0100    0.0015
##     60        1.1560             nan     0.0100    0.0005
##     80        1.1095             nan     0.0100    0.0006
##    100        1.0745             nan     0.0100    0.0006
##    120        1.0428             nan     0.0100    0.0006
##    140        1.0154             nan     0.0100    0.0001
##    150        1.0046             nan     0.0100    0.0003
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3725             nan     0.0100    0.0013
##      2        1.3669             nan     0.0100    0.0027
##      3        1.3623             nan     0.0100    0.0026
##      4        1.3579             nan     0.0100    0.0015
##      5        1.3528             nan     0.0100    0.0026
##      6        1.3475             nan     0.0100    0.0025
##      7        1.3435             nan     0.0100    0.0017
##      8        1.3387             nan     0.0100    0.0024
##      9        1.3345             nan     0.0100    0.0017
##     10        1.3294             nan     0.0100    0.0026
##     20        1.2861             nan     0.0100    0.0020
##     40        1.2138             nan     0.0100    0.0012
##     60        1.1570             nan     0.0100    0.0005
##     80        1.1123             nan     0.0100    0.0006
##    100        1.0740             nan     0.0100    0.0007
##    120        1.0428             nan     0.0100    0.0002
##    140        1.0155             nan     0.0100    0.0003
##    150        1.0039             nan     0.0100    0.0005
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3722             nan     0.0100    0.0017
##      2        1.3685             nan     0.0100    0.0017
##      3        1.3632             nan     0.0100    0.0027
##      4        1.3572             nan     0.0100    0.0024
##      5        1.3527             nan     0.0100    0.0020
##      6        1.3491             nan     0.0100    0.0009
##      7        1.3437             nan     0.0100    0.0025
##      8        1.3386             nan     0.0100    0.0025
##      9        1.3341             nan     0.0100    0.0016
##     10        1.3288             nan     0.0100    0.0024
##     20        1.2842             nan     0.0100    0.0020
##     40        1.2118             nan     0.0100    0.0016
##     60        1.1566             nan     0.0100    0.0007
##     80        1.1128             nan     0.0100    0.0006
##    100        1.0756             nan     0.0100    0.0006
##    120        1.0438             nan     0.0100    0.0004
##    140        1.0180             nan     0.0100    0.0003
##    150        1.0058             nan     0.0100    0.0006
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3691             nan     0.0100    0.0035
##      2        1.3606             nan     0.0100    0.0039
##      3        1.3527             nan     0.0100    0.0035
##      4        1.3468             nan     0.0100    0.0021
##      5        1.3393             nan     0.0100    0.0028
##      6        1.3313             nan     0.0100    0.0032
##      7        1.3235             nan     0.0100    0.0030
##      8        1.3161             nan     0.0100    0.0032
##      9        1.3084             nan     0.0100    0.0039
##     10        1.3027             nan     0.0100    0.0029
##     20        1.2375             nan     0.0100    0.0021
##     40        1.1392             nan     0.0100    0.0018
##     60        1.0599             nan     0.0100    0.0012
##     80        0.9967             nan     0.0100    0.0008
##    100        0.9457             nan     0.0100    0.0007
##    120        0.8977             nan     0.0100    0.0011
##    140        0.8598             nan     0.0100    0.0002
##    150        0.8436             nan     0.0100    0.0004
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3700             nan     0.0100    0.0024
##      2        1.3614             nan     0.0100    0.0040
##      3        1.3532             nan     0.0100    0.0038
##      4        1.3462             nan     0.0100    0.0031
##      5        1.3395             nan     0.0100    0.0026
##      6        1.3325             nan     0.0100    0.0030
##      7        1.3247             nan     0.0100    0.0033
##      8        1.3178             nan     0.0100    0.0034
##      9        1.3101             nan     0.0100    0.0027
##     10        1.3034             nan     0.0100    0.0032
##     20        1.2403             nan     0.0100    0.0028
##     40        1.1370             nan     0.0100    0.0017
##     60        1.0596             nan     0.0100    0.0013
##     80        1.0021             nan     0.0100    0.0005
##    100        0.9521             nan     0.0100    0.0004
##    120        0.9115             nan     0.0100    0.0004
##    140        0.8760             nan     0.0100    0.0003
##    150        0.8602             nan     0.0100   -0.0002
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3684             nan     0.0100    0.0037
##      2        1.3610             nan     0.0100    0.0033
##      3        1.3543             nan     0.0100    0.0026
##      4        1.3462             nan     0.0100    0.0036
##      5        1.3391             nan     0.0100    0.0031
##      6        1.3313             nan     0.0100    0.0037
##      7        1.3239             nan     0.0100    0.0038
##      8        1.3164             nan     0.0100    0.0036
##      9        1.3089             nan     0.0100    0.0036
##     10        1.3027             nan     0.0100    0.0030
##     20        1.2417             nan     0.0100    0.0027
##     40        1.1400             nan     0.0100    0.0015
##     60        1.0673             nan     0.0100    0.0013
##     80        1.0041             nan     0.0100    0.0010
##    100        0.9557             nan     0.0100    0.0005
##    120        0.9120             nan     0.0100    0.0008
##    140        0.8780             nan     0.0100    0.0000
##    150        0.8607             nan     0.0100    0.0000
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3675             nan     0.0100    0.0036
##      2        1.3595             nan     0.0100    0.0030
##      3        1.3507             nan     0.0100    0.0035
##      4        1.3418             nan     0.0100    0.0035
##      5        1.3339             nan     0.0100    0.0027
##      6        1.3249             nan     0.0100    0.0038
##      7        1.3174             nan     0.0100    0.0038
##      8        1.3090             nan     0.0100    0.0034
##      9        1.2998             nan     0.0100    0.0032
##     10        1.2926             nan     0.0100    0.0028
##     20        1.2155             nan     0.0100    0.0024
##     40        1.0921             nan     0.0100    0.0015
##     60        1.0034             nan     0.0100    0.0016
##     80        0.9339             nan     0.0100    0.0005
##    100        0.8725             nan     0.0100    0.0002
##    120        0.8212             nan     0.0100    0.0006
##    140        0.7746             nan     0.0100   -0.0002
##    150        0.7529             nan     0.0100    0.0002
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3675             nan     0.0100    0.0038
##      2        1.3590             nan     0.0100    0.0033
##      3        1.3509             nan     0.0100    0.0034
##      4        1.3429             nan     0.0100    0.0028
##      5        1.3340             nan     0.0100    0.0038
##      6        1.3246             nan     0.0100    0.0034
##      7        1.3161             nan     0.0100    0.0040
##      8        1.3088             nan     0.0100    0.0023
##      9        1.3002             nan     0.0100    0.0039
##     10        1.2915             nan     0.0100    0.0040
##     20        1.2228             nan     0.0100    0.0017
##     40        1.1107             nan     0.0100    0.0012
##     60        1.0239             nan     0.0100    0.0007
##     80        0.9550             nan     0.0100    0.0004
##    100        0.8951             nan     0.0100    0.0012
##    120        0.8466             nan     0.0100    0.0003
##    140        0.8100             nan     0.0100   -0.0001
##    150        0.7932             nan     0.0100    0.0002
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3695             nan     0.0100    0.0033
##      2        1.3612             nan     0.0100    0.0028
##      3        1.3528             nan     0.0100    0.0039
##      4        1.3444             nan     0.0100    0.0034
##      5        1.3391             nan     0.0100    0.0019
##      6        1.3322             nan     0.0100    0.0031
##      7        1.3260             nan     0.0100    0.0029
##      8        1.3188             nan     0.0100    0.0027
##      9        1.3110             nan     0.0100    0.0026
##     10        1.3045             nan     0.0100    0.0029
##     20        1.2382             nan     0.0100    0.0029
##     40        1.1427             nan     0.0100    0.0019
##     60        1.0622             nan     0.0100    0.0008
##     80        0.9989             nan     0.0100    0.0004
##    100        0.9505             nan     0.0100    0.0002
##    120        0.9089             nan     0.0100    0.0005
##    140        0.8708             nan     0.0100   -0.0002
##    150        0.8548             nan     0.0100   -0.0002
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3743             nan     0.0100    0.0015
##      2        1.3710             nan     0.0100    0.0013
##      3        1.3672             nan     0.0100    0.0017
##      4        1.3633             nan     0.0100    0.0022
##      5        1.3593             nan     0.0100    0.0011
##      6        1.3550             nan     0.0100    0.0021
##      7        1.3519             nan     0.0100    0.0010
##      8        1.3491             nan     0.0100    0.0010
##      9        1.3450             nan     0.0100    0.0021
##     10        1.3402             nan     0.0100    0.0020
##     20        1.3046             nan     0.0100    0.0011
##     40        1.2401             nan     0.0100    0.0013
##     60        1.1920             nan     0.0100    0.0011
##     80        1.1484             nan     0.0100    0.0008
##    100        1.1143             nan     0.0100    0.0008
##    120        1.0829             nan     0.0100    0.0004
##    140        1.0572             nan     0.0100    0.0005
##    150        1.0441             nan     0.0100    0.0004
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3719             nan     0.0100    0.0022
##      2        1.3674             nan     0.0100    0.0020
##      3        1.3628             nan     0.0100    0.0021
##      4        1.3590             nan     0.0100    0.0013
##      5        1.3559             nan     0.0100    0.0013
##      6        1.3517             nan     0.0100    0.0021
##      7        1.3483             nan     0.0100    0.0016
##      8        1.3452             nan     0.0100    0.0015
##      9        1.3414             nan     0.0100    0.0018
##     10        1.3373             nan     0.0100    0.0013
##     20        1.3046             nan     0.0100    0.0017
##     40        1.2454             nan     0.0100    0.0014
##     60        1.1955             nan     0.0100    0.0003
##     80        1.1513             nan     0.0100    0.0003
##    100        1.1153             nan     0.0100    0.0001
##    120        1.0855             nan     0.0100    0.0006
##    140        1.0584             nan     0.0100    0.0003
##    150        1.0471             nan     0.0100   -0.0002
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3728             nan     0.0100    0.0022
##      2        1.3691             nan     0.0100    0.0008
##      3        1.3654             nan     0.0100    0.0015
##      4        1.3610             nan     0.0100    0.0021
##      5        1.3578             nan     0.0100    0.0010
##      6        1.3536             nan     0.0100    0.0021
##      7        1.3486             nan     0.0100    0.0021
##      8        1.3445             nan     0.0100    0.0020
##      9        1.3409             nan     0.0100    0.0006
##     10        1.3372             nan     0.0100    0.0019
##     20        1.3023             nan     0.0100    0.0012
##     40        1.2411             nan     0.0100    0.0010
##     60        1.1936             nan     0.0100    0.0005
##     80        1.1541             nan     0.0100    0.0007
##    100        1.1190             nan     0.0100    0.0007
##    120        1.0878             nan     0.0100    0.0005
##    140        1.0641             nan     0.0100   -0.0005
##    150        1.0514             nan     0.0100    0.0004
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3710             nan     0.0100    0.0031
##      2        1.3648             nan     0.0100    0.0032
##      3        1.3577             nan     0.0100    0.0022
##      4        1.3517             nan     0.0100    0.0021
##      5        1.3441             nan     0.0100    0.0030
##      6        1.3368             nan     0.0100    0.0030
##      7        1.3311             nan     0.0100    0.0016
##      8        1.3251             nan     0.0100    0.0026
##      9        1.3193             nan     0.0100    0.0019
##     10        1.3135             nan     0.0100    0.0024
##     20        1.2591             nan     0.0100    0.0023
##     40        1.1678             nan     0.0100    0.0017
##     60        1.0957             nan     0.0100    0.0008
##     80        1.0369             nan     0.0100    0.0010
##    100        0.9855             nan     0.0100    0.0005
##    120        0.9437             nan     0.0100    0.0005
##    140        0.9042             nan     0.0100    0.0001
##    150        0.8872             nan     0.0100    0.0002
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3729             nan     0.0100    0.0013
##      2        1.3665             nan     0.0100    0.0025
##      3        1.3585             nan     0.0100    0.0027
##      4        1.3521             nan     0.0100    0.0023
##      5        1.3469             nan     0.0100    0.0014
##      6        1.3398             nan     0.0100    0.0031
##      7        1.3329             nan     0.0100    0.0024
##      8        1.3262             nan     0.0100    0.0023
##      9        1.3198             nan     0.0100    0.0025
##     10        1.3127             nan     0.0100    0.0027
##     20        1.2568             nan     0.0100    0.0019
##     40        1.1694             nan     0.0100    0.0009
##     60        1.0949             nan     0.0100    0.0012
##     80        1.0352             nan     0.0100    0.0007
##    100        0.9856             nan     0.0100    0.0001
##    120        0.9435             nan     0.0100    0.0005
##    140        0.9104             nan     0.0100    0.0000
##    150        0.8935             nan     0.0100    0.0003
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3716             nan     0.0100    0.0016
##      2        1.3665             nan     0.0100    0.0017
##      3        1.3611             nan     0.0100    0.0014
##      4        1.3542             nan     0.0100    0.0034
##      5        1.3477             nan     0.0100    0.0021
##      6        1.3423             nan     0.0100    0.0018
##      7        1.3363             nan     0.0100    0.0026
##      8        1.3288             nan     0.0100    0.0027
##      9        1.3235             nan     0.0100    0.0016
##     10        1.3174             nan     0.0100    0.0019
##     20        1.2606             nan     0.0100    0.0009
##     40        1.1697             nan     0.0100    0.0016
##     60        1.0984             nan     0.0100    0.0005
##     80        1.0391             nan     0.0100    0.0010
##    100        0.9910             nan     0.0100    0.0002
##    120        0.9528             nan     0.0100    0.0007
##    140        0.9180             nan     0.0100    0.0001
##    150        0.9012             nan     0.0100    0.0002
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3699             nan     0.0100    0.0027
##      2        1.3622             nan     0.0100    0.0032
##      3        1.3534             nan     0.0100    0.0038
##      4        1.3450             nan     0.0100    0.0030
##      5        1.3370             nan     0.0100    0.0030
##      6        1.3291             nan     0.0100    0.0031
##      7        1.3208             nan     0.0100    0.0032
##      8        1.3145             nan     0.0100    0.0022
##      9        1.3073             nan     0.0100    0.0022
##     10        1.2988             nan     0.0100    0.0032
##     20        1.2362             nan     0.0100    0.0005
##     40        1.1268             nan     0.0100    0.0010
##     60        1.0346             nan     0.0100    0.0013
##     80        0.9616             nan     0.0100    0.0003
##    100        0.9015             nan     0.0100    0.0002
##    120        0.8512             nan     0.0100    0.0008
##    140        0.8063             nan     0.0100   -0.0006
##    150        0.7857             nan     0.0100   -0.0002
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3697             nan     0.0100    0.0031
##      2        1.3637             nan     0.0100    0.0013
##      3        1.3564             nan     0.0100    0.0027
##      4        1.3487             nan     0.0100    0.0027
##      5        1.3425             nan     0.0100    0.0020
##      6        1.3345             nan     0.0100    0.0035
##      7        1.3274             nan     0.0100    0.0026
##      8        1.3206             nan     0.0100    0.0024
##      9        1.3138             nan     0.0100    0.0024
##     10        1.3081             nan     0.0100    0.0020
##     20        1.2429             nan     0.0100    0.0020
##     40        1.1362             nan     0.0100    0.0014
##     60        1.0523             nan     0.0100    0.0008
##     80        0.9864             nan     0.0100    0.0005
##    100        0.9332             nan     0.0100    0.0000
##    120        0.8845             nan     0.0100    0.0011
##    140        0.8453             nan     0.0100    0.0003
##    150        0.8268             nan     0.0100    0.0002
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3705             nan     0.0100    0.0033
##      2        1.3649             nan     0.0100    0.0022
##      3        1.3583             nan     0.0100    0.0022
##      4        1.3512             nan     0.0100    0.0028
##      5        1.3466             nan     0.0100    0.0015
##      6        1.3397             nan     0.0100    0.0028
##      7        1.3339             nan     0.0100    0.0022
##      8        1.3270             nan     0.0100    0.0022
##      9        1.3212             nan     0.0100    0.0020
##     10        1.3153             nan     0.0100    0.0022
##     20        1.2604             nan     0.0100    0.0020
##     40        1.1626             nan     0.0100    0.0017
##     60        1.0927             nan     0.0100    0.0016
##     80        1.0310             nan     0.0100    0.0012
##    100        0.9815             nan     0.0100    0.0001
##    120        0.9415             nan     0.0100   -0.0005
##    140        0.9043             nan     0.0100    0.0004
##    150        0.8872             nan     0.0100    0.0002
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3731             nan     0.0100    0.0016
##      2        1.3685             nan     0.0100    0.0021
##      3        1.3635             nan     0.0100    0.0019
##      4        1.3597             nan     0.0100    0.0014
##      5        1.3555             nan     0.0100    0.0019
##      6        1.3520             nan     0.0100    0.0015
##      7        1.3485             nan     0.0100    0.0013
##      8        1.3437             nan     0.0100    0.0017
##      9        1.3394             nan     0.0100    0.0020
##     10        1.3352             nan     0.0100    0.0019
##     20        1.2998             nan     0.0100    0.0009
##     40        1.2390             nan     0.0100    0.0010
##     60        1.1896             nan     0.0100    0.0008
##     80        1.1505             nan     0.0100   -0.0004
##    100        1.1147             nan     0.0100    0.0002
##    120        1.0826             nan     0.0100    0.0003
##    140        1.0560             nan     0.0100    0.0001
##    150        1.0443             nan     0.0100    0.0004
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3727             nan     0.0100    0.0017
##      2        1.3686             nan     0.0100    0.0017
##      3        1.3638             nan     0.0100    0.0021
##      4        1.3599             nan     0.0100    0.0014
##      5        1.3553             nan     0.0100    0.0020
##      6        1.3510             nan     0.0100    0.0019
##      7        1.3474             nan     0.0100    0.0020
##      8        1.3436             nan     0.0100    0.0019
##      9        1.3395             nan     0.0100    0.0014
##     10        1.3352             nan     0.0100    0.0012
##     20        1.2980             nan     0.0100    0.0011
##     40        1.2358             nan     0.0100    0.0013
##     60        1.1863             nan     0.0100    0.0009
##     80        1.1431             nan     0.0100    0.0001
##    100        1.1072             nan     0.0100    0.0006
##    120        1.0784             nan     0.0100    0.0004
##    140        1.0527             nan     0.0100    0.0002
##    150        1.0411             nan     0.0100    0.0002
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3710             nan     0.0100    0.0020
##      2        1.3675             nan     0.0100    0.0016
##      3        1.3633             nan     0.0100    0.0011
##      4        1.3589             nan     0.0100    0.0018
##      5        1.3551             nan     0.0100    0.0016
##      6        1.3515             nan     0.0100    0.0016
##      7        1.3481             nan     0.0100    0.0009
##      8        1.3442             nan     0.0100    0.0019
##      9        1.3413             nan     0.0100    0.0006
##     10        1.3378             nan     0.0100    0.0015
##     20        1.3033             nan     0.0100    0.0011
##     40        1.2426             nan     0.0100    0.0013
##     60        1.1923             nan     0.0100    0.0011
##     80        1.1476             nan     0.0100    0.0008
##    100        1.1131             nan     0.0100    0.0006
##    120        1.0814             nan     0.0100    0.0004
##    140        1.0538             nan     0.0100    0.0001
##    150        1.0420             nan     0.0100    0.0004
##
```

```
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3683             nan     0.0100    0.0032
##      2        1.3605             nan     0.0100    0.0030
##      3        1.3546             nan     0.0100    0.0019
##      4        1.3471             nan     0.0100    0.0028
##      5        1.3400             nan     0.0100    0.0033
##      6        1.3345             nan     0.0100    0.0020
##      7        1.3281             nan     0.0100    0.0019
##      8        1.3210             nan     0.0100    0.0024
##      9        1.3137             nan     0.0100    0.0027
##     10        1.3081             nan     0.0100    0.0022
##     20        1.2511             nan     0.0100    0.0024
##     40        1.1579             nan     0.0100    0.0001
##     60        1.0836             nan     0.0100    0.0014
##     80        1.0215             nan     0.0100    0.0006
##    100        0.9698             nan     0.0100    0.0004
##    120        0.9259             nan     0.0100   -0.0000
##    140        0.8886             nan     0.0100    0.0004
##    150        0.8728             nan     0.0100    0.0000
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3708             nan     0.0100    0.0014
##      2        1.3633             nan     0.0100    0.0038
##      3        1.3569             nan     0.0100    0.0022
##      4        1.3499             nan     0.0100    0.0026
##      5        1.3434             nan     0.0100    0.0026
##      6        1.3355             nan     0.0100    0.0027
##      7        1.3293             nan     0.0100    0.0016
##      8        1.3218             nan     0.0100    0.0034
##      9        1.3160             nan     0.0100    0.0020
##     10        1.3091             nan     0.0100    0.0029
##     20        1.2501             nan     0.0100    0.0012
##     40        1.1552             nan     0.0100    0.0017
##     60        1.0824             nan     0.0100    0.0003
##     80        1.0227             nan     0.0100    0.0012
##    100        0.9751             nan     0.0100    0.0008
##    120        0.9341             nan     0.0100    0.0000
##    140        0.8994             nan     0.0100    0.0004
##    150        0.8823             nan     0.0100   -0.0001
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3702             nan     0.0100    0.0030
##      2        1.3651             nan     0.0100    0.0015
##      3        1.3588             nan     0.0100    0.0028
##      4        1.3536             nan     0.0100    0.0018
##      5        1.3468             nan     0.0100    0.0032
##      6        1.3403             nan     0.0100    0.0019
##      7        1.3325             nan     0.0100    0.0035
##      8        1.3256             nan     0.0100    0.0035
##      9        1.3194             nan     0.0100    0.0022
##     10        1.3139             nan     0.0100    0.0021
##     20        1.2565             nan     0.0100    0.0021
##     40        1.1614             nan     0.0100    0.0011
##     60        1.0893             nan     0.0100    0.0010
##     80        1.0298             nan     0.0100    0.0008
##    100        0.9795             nan     0.0100    0.0009
##    120        0.9383             nan     0.0100    0.0007
##    140        0.9038             nan     0.0100   -0.0003
##    150        0.8862             nan     0.0100    0.0005
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3682             nan     0.0100    0.0028
##      2        1.3605             nan     0.0100    0.0025
##      3        1.3517             nan     0.0100    0.0028
##      4        1.3439             nan     0.0100    0.0033
##      5        1.3363             nan     0.0100    0.0032
##      6        1.3286             nan     0.0100    0.0026
##      7        1.3208             nan     0.0100    0.0030
##      8        1.3130             nan     0.0100    0.0035
##      9        1.3054             nan     0.0100    0.0028
##     10        1.2984             nan     0.0100    0.0023
##     20        1.2290             nan     0.0100    0.0014
##     40        1.1183             nan     0.0100    0.0012
##     60        1.0264             nan     0.0100    0.0012
##     80        0.9541             nan     0.0100    0.0005
##    100        0.8938             nan     0.0100    0.0006
##    120        0.8432             nan     0.0100   -0.0001
##    140        0.7953             nan     0.0100   -0.0001
##    150        0.7768             nan     0.0100    0.0006
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3683             nan     0.0100    0.0033
##      2        1.3608             nan     0.0100    0.0029
##      3        1.3541             nan     0.0100    0.0028
##      4        1.3466             nan     0.0100    0.0029
##      5        1.3381             nan     0.0100    0.0038
##      6        1.3309             nan     0.0100    0.0030
##      7        1.3248             nan     0.0100    0.0022
##      8        1.3187             nan     0.0100    0.0021
##      9        1.3117             nan     0.0100    0.0035
##     10        1.3043             nan     0.0100    0.0034
##     20        1.2357             nan     0.0100    0.0020
##     40        1.1307             nan     0.0100    0.0016
##     60        1.0508             nan     0.0100    0.0001
##     80        0.9823             nan     0.0100    0.0010
##    100        0.9245             nan     0.0100    0.0005
##    120        0.8771             nan     0.0100   -0.0001
##    140        0.8325             nan     0.0100    0.0004
##    150        0.8131             nan     0.0100   -0.0000
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3689             nan     0.0100    0.0022
##      2        1.3627             nan     0.0100    0.0021
##      3        1.3554             nan     0.0100    0.0031
##      4        1.3488             nan     0.0100    0.0019
##      5        1.3419             nan     0.0100    0.0025
##      6        1.3363             nan     0.0100    0.0017
##      7        1.3303             nan     0.0100    0.0022
##      8        1.3230             nan     0.0100    0.0031
##      9        1.3158             nan     0.0100    0.0029
##     10        1.3090             nan     0.0100    0.0032
##     20        1.2522             nan     0.0100    0.0023
##     40        1.1528             nan     0.0100    0.0013
##     60        1.0806             nan     0.0100    0.0008
##     80        1.0247             nan     0.0100    0.0011
##    100        0.9745             nan     0.0100    0.0002
##    120        0.9311             nan     0.0100    0.0000
##    140        0.8956             nan     0.0100   -0.0003
##    150        0.8797             nan     0.0100   -0.0001
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3728             nan     0.0100    0.0025
##      2        1.3678             nan     0.0100    0.0024
##      3        1.3633             nan     0.0100    0.0014
##      4        1.3579             nan     0.0100    0.0023
##      5        1.3537             nan     0.0100    0.0023
##      6        1.3490             nan     0.0100    0.0023
##      7        1.3445             nan     0.0100    0.0023
##      8        1.3412             nan     0.0100    0.0013
##      9        1.3362             nan     0.0100    0.0022
##     10        1.3310             nan     0.0100    0.0021
##     20        1.2893             nan     0.0100    0.0017
##     40        1.2261             nan     0.0100    0.0009
##     60        1.1728             nan     0.0100    0.0011
##     80        1.1312             nan     0.0100    0.0005
##    100        1.0971             nan     0.0100    0.0002
##    120        1.0661             nan     0.0100    0.0004
##    140        1.0389             nan     0.0100   -0.0002
##    150        1.0265             nan     0.0100    0.0003
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3730             nan     0.0100    0.0015
##      2        1.3686             nan     0.0100    0.0018
##      3        1.3634             nan     0.0100    0.0025
##      4        1.3594             nan     0.0100    0.0014
##      5        1.3574             nan     0.0100    0.0005
##      6        1.3550             nan     0.0100    0.0007
##      7        1.3499             nan     0.0100    0.0024
##      8        1.3451             nan     0.0100    0.0023
##      9        1.3406             nan     0.0100    0.0023
##     10        1.3363             nan     0.0100    0.0021
##     20        1.2954             nan     0.0100    0.0019
##     40        1.2300             nan     0.0100    0.0014
##     60        1.1766             nan     0.0100    0.0011
##     80        1.1328             nan     0.0100    0.0007
##    100        1.0956             nan     0.0100    0.0003
##    120        1.0640             nan     0.0100    0.0006
##    140        1.0377             nan     0.0100    0.0004
##    150        1.0262             nan     0.0100    0.0002
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3713             nan     0.0100    0.0024
##      2        1.3662             nan     0.0100    0.0023
##      3        1.3613             nan     0.0100    0.0016
##      4        1.3580             nan     0.0100    0.0012
##      5        1.3541             nan     0.0100    0.0014
##      6        1.3493             nan     0.0100    0.0024
##      7        1.3441             nan     0.0100    0.0023
##      8        1.3383             nan     0.0100    0.0021
##      9        1.3337             nan     0.0100    0.0022
##     10        1.3293             nan     0.0100    0.0022
##     20        1.2901             nan     0.0100    0.0013
##     40        1.2262             nan     0.0100    0.0009
##     60        1.1721             nan     0.0100    0.0009
##     80        1.1258             nan     0.0100    0.0006
##    100        1.0917             nan     0.0100    0.0005
##    120        1.0605             nan     0.0100    0.0004
##    140        1.0351             nan     0.0100    0.0003
##    150        1.0231             nan     0.0100    0.0004
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3702             nan     0.0100    0.0031
##      2        1.3632             nan     0.0100    0.0022
##      3        1.3558             nan     0.0100    0.0032
##      4        1.3485             nan     0.0100    0.0027
##      5        1.3425             nan     0.0100    0.0027
##      6        1.3355             nan     0.0100    0.0031
##      7        1.3289             nan     0.0100    0.0031
##      8        1.3226             nan     0.0100    0.0029
##      9        1.3156             nan     0.0100    0.0031
##     10        1.3089             nan     0.0100    0.0030
##     20        1.2525             nan     0.0100    0.0021
##     40        1.1559             nan     0.0100    0.0013
##     60        1.0812             nan     0.0100    0.0012
##     80        1.0191             nan     0.0100    0.0003
##    100        0.9653             nan     0.0100    0.0001
##    120        0.9189             nan     0.0100    0.0008
##    140        0.8805             nan     0.0100   -0.0003
##    150        0.8620             nan     0.0100    0.0005
## 
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3709             nan     0.0100    0.0027
##      2        1.3652             nan     0.0100    0.0021
##      3        1.3564             nan     0.0100    0.0032
##      4        1.3488             nan     0.0100    0.0029
##      5        1.3429             nan     0.0100    0.0017
##      6        1.3378             nan     0.0100    0.0017
##      7        1.3307             nan     0.0100    0.0030
##      8        1.3236             nan     0.0100    0.0028
##      9        1.3167             nan     0.0100    0.0026
##     10        1.3094             nan     0.0100    0.0024
##     20        1.2521             nan     0.0100    0.0024
##     40        1.1563             nan     0.0100    0.0014
##     60        1.0824             nan     0.0100    0.0008
##     80        1.0235             nan     0.0100    0.0004
##    100        0.9717             nan     0.0100    0.0002
##    120        0.9302             nan     0.0100    0.0006
##    140        0.8955             nan     0.0100    0.0002
##    150        0.8787             nan     0.0100    0.0002
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3700             nan     0.0100    0.0031
##      2        1.3623             nan     0.0100    0.0027
##      3        1.3557             nan     0.0100    0.0030
##      4        1.3474             nan     0.0100    0.0037
##      5        1.3419             nan     0.0100    0.0023
##      6        1.3347             nan     0.0100    0.0037
##      7        1.3282             nan     0.0100    0.0029
##      8        1.3221             nan     0.0100    0.0022
##      9        1.3151             nan     0.0100    0.0033
##     10        1.3090             nan     0.0100    0.0027
##     20        1.2501             nan     0.0100    0.0016
##     40        1.1544             nan     0.0100    0.0015
##     60        1.0799             nan     0.0100    0.0011
##     80        1.0230             nan     0.0100    0.0008
##    100        0.9753             nan     0.0100    0.0004
##    120        0.9359             nan     0.0100   -0.0001
##    140        0.9028             nan     0.0100    0.0001
##    150        0.8883             nan     0.0100   -0.0000
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3678             nan     0.0100    0.0038
##      2        1.3603             nan     0.0100    0.0025
##      3        1.3510             nan     0.0100    0.0032
##      4        1.3432             nan     0.0100    0.0033
##      5        1.3345             nan     0.0100    0.0035
##      6        1.3284             nan     0.0100    0.0021
##      7        1.3213             nan     0.0100    0.0024
##      8        1.3141             nan     0.0100    0.0023
##      9        1.3066             nan     0.0100    0.0029
##     10        1.2998             nan     0.0100    0.0020
##     20        1.2301             nan     0.0100    0.0026
##     40        1.1166             nan     0.0100    0.0013
##     60        1.0232             nan     0.0100    0.0015
##     80        0.9488             nan     0.0100    0.0005
##    100        0.8926             nan     0.0100    0.0005
##    120        0.8404             nan     0.0100    0.0004
##    140        0.7948             nan     0.0100    0.0003
##    150        0.7748             nan     0.0100    0.0004
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3695             nan     0.0100    0.0030
##      2        1.3609             nan     0.0100    0.0032
##      3        1.3540             nan     0.0100    0.0025
##      4        1.3454             nan     0.0100    0.0042
##      5        1.3384             nan     0.0100    0.0024
##      6        1.3302             nan     0.0100    0.0029
##      7        1.3233             nan     0.0100    0.0029
##      8        1.3153             nan     0.0100    0.0032
##      9        1.3084             nan     0.0100    0.0022
##     10        1.3017             nan     0.0100    0.0023
##     20        1.2367             nan     0.0100    0.0024
##     40        1.1306             nan     0.0100    0.0019
##     60        1.0479             nan     0.0100    0.0005
##     80        0.9795             nan     0.0100    0.0012
##    100        0.9248             nan     0.0100    0.0011
##    120        0.8766             nan     0.0100    0.0002
##    140        0.8349             nan     0.0100   -0.0004
##    150        0.8177             nan     0.0100   -0.0002
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3709             nan     0.0100    0.0029
##      2        1.3629             nan     0.0100    0.0037
##      3        1.3555             nan     0.0100    0.0030
##      4        1.3490             nan     0.0100    0.0021
##      5        1.3427             nan     0.0100    0.0024
##      6        1.3359             nan     0.0100    0.0025
##      7        1.3295             nan     0.0100    0.0020
##      8        1.3228             nan     0.0100    0.0029
##      9        1.3157             nan     0.0100    0.0029
##     10        1.3111             nan     0.0100    0.0014
##     20        1.2527             nan     0.0100    0.0025
##     40        1.1560             nan     0.0100    0.0018
##     60        1.0800             nan     0.0100    0.0004
##     80        1.0213             nan     0.0100    0.0007
##    100        0.9693             nan     0.0100    0.0011
##    120        0.9267             nan     0.0100   -0.0002
##    140        0.8909             nan     0.0100    0.0003
##    150        0.8758             nan     0.0100    0.0001
##
## Iter   TrainDeviance   ValidDeviance   StepSize   Improve
##      1        1.3684             nan     0.0100    0.0041
##      2        1.3596             nan     0.0100    0.0039
##      3        1.3524             nan     0.0100    0.0027
##      4        1.3442             nan     0.0100    0.0039
##      5        1.3376             nan     0.0100    0.0028
##      6        1.3299             nan     0.0100    0.0033
##      7        1.3227             nan     0.0100    0.0028
##      8        1.3149             nan     0.0100    0.0028
##      9        1.3075             nan     0.0100    0.0030
##     10        1.3017             nan     0.0100    0.0017
##     20        1.2397             nan     0.0100    0.0016
##     40        1.1378             nan     0.0100    0.0014
##     60        1.0538             nan     0.0100    0.0011
##     80        0.9888             nan     0.0100    0.0007
##    100        0.9338             nan     0.0100    0.0010
##    120        0.8894             nan     0.0100    0.0002
##    140        0.8487             nan     0.0100   -0.0002
##    150        0.8322             nan     0.0100   -0.0002
```

```
## Stochastic Gradient Boosting
##
## 239 samples
##  11 predictor
##   2 classes: 'no', 'yes'
##
## No pre-processing
## Resampling: Cross-Validated (5 fold)
## Summary of sample sizes: 192, 191, 190, 191, 192
## Resampling results across tuning parameters:
##
##   interaction.depth  n.minobsinnode  Accuracy   Kappa
##   1                   5              0.7570560  0.5018753
##   1                  10              0.7442086  0.4762721
##   1                  15              0.7403857  0.4689432
##   3                   5              0.7531517  0.4978995
##   3                  10              0.7489850  0.4889287
##   3                  15              0.7489886  0.4895727
##   5                   5              0.7493324  0.4912688
##   5                  10              0.7660027  0.5259506
##   5                  15              0.7448184  0.4804674
##
## Tuning parameter 'n.trees' was held constant at a value of 150
## Tuning
##  parameter 'shrinkage' was held constant at a value of 0.01
## Accuracy was used to select the optimal model using the largest value.
## The final values used for the model were n.trees = 150, interaction.depth =
##  5, shrinkage = 0.01 and n.minobsinnode = 10.
```

```r
# Training Error =0.5027174
predict_train <- predict(boost_tuned, n.trees = 1000, type = "prob", newdata = heart_train)
predicted_train_classes <- ifelse(predict_train[, 2] > 0.5, 1, 0)
mean(predicted_train_classes != heart_test$num)
```

```
## Warning in predicted_train_classes != heart_test$num: longer object length is
## not a multiple of shorter object length
```

```
## [1] 0.5062762
```

```r
# Testing Error = 0.1793478
predict_test <- predict(boost_tuned, n.trees = 1000, type = "prob", newdata = heart_test)
predicted_test_classes <- ifelse(predict_test[, 2] > 0.5, 1, 0)
mean(predicted_test_classes != heart_test$num)
```

```
## [1] 0.15
```

```r
# Confusion Matrix
predictions_test <- factor(predicted_test_classes, levels = c(0, 1), labels = c("no", "yes"))
conf_matrix_test <- confusionMatrix(predictions_test, y_test,mode = "everything")
print(conf_matrix_test)
```

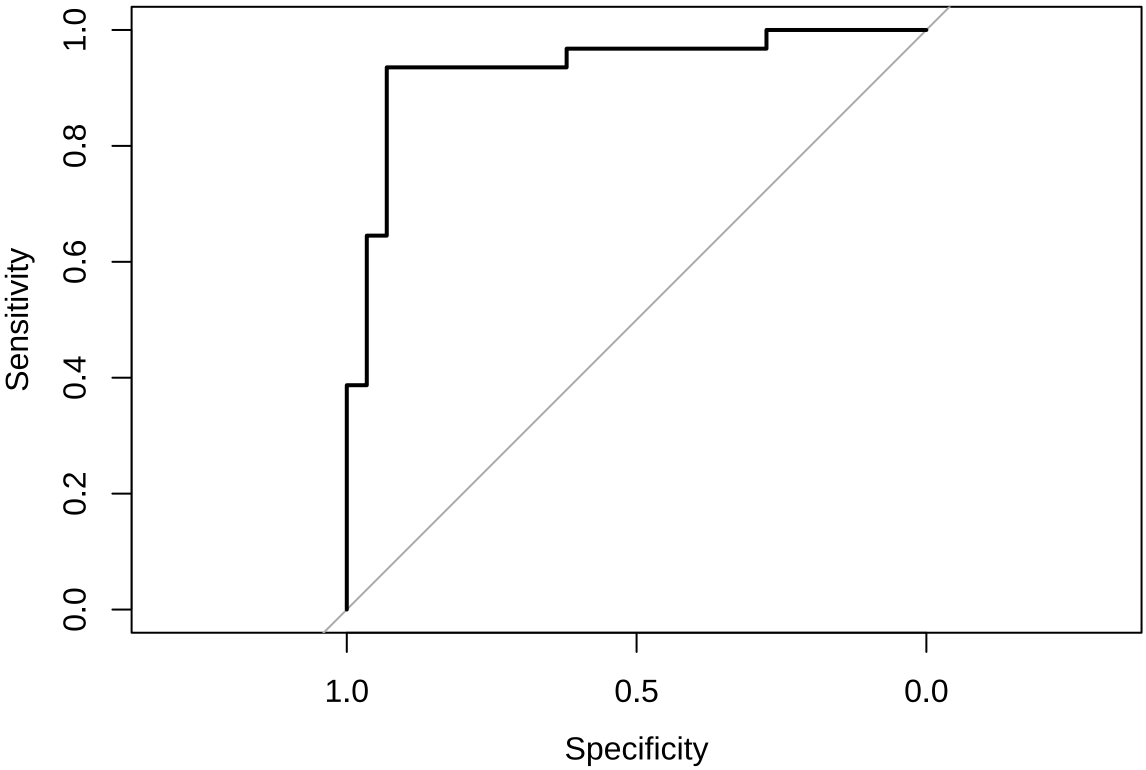
```
## Confusion Matrix and Statistics
##
##           Reference
## Prediction no yes
##        no  27   7
##        yes  2  24
##
##                 Accuracy : 0.85
##                   95% CI : (0.7343, 0.929)
##     No Information Rate : 0.5167
##     P-Value [Acc > NIR] : 6.136e-08
##
##                   Kappa : 0.7013
##
##  Mcnemar's Test P-Value : 0.1824
##
##             Sensitivity : 0.9310
##             Specificity : 0.7742
##          Pos Pred Value : 0.7941
##          Neg Pred Value : 0.9231
##               Precision : 0.7941
##                  Recall : 0.9310
##                      F1 : 0.8571
##              Prevalence : 0.4833
##          Detection Rate : 0.4500
##    Detection Prevalence : 0.5667
##       Balanced Accuracy : 0.8526
##
##        'Positive' Class : no
##
```

```
# accuracy =  0.8207
# F1 = 0.7519

# AUCROC
predictions.prob <- predict(boost_tuned, X_test, type = "prob")
roc.tuned.gbm <- roc(response = y_test, predictor = predictions.prob[,2], plot = TRUE)
```

```
## Setting levels: control = no, case = yes
```

```
## Setting direction: controls < cases
```



```
print(auc(roc.tuned.gbm))
```

```
## Area under the curve: 0.9355
```

```
# auc = 0.904
```