

P8106_HW4

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04/11/2025

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Loading libraries

```
# Load libraries
library(tidyverse)
library(tidymodels)
library(caret)
library(ggplot2)
library(rpart)
library(rpart.plot)
library(ranger)
library(gbm)
library(rsample)
library(pROC)
```

Part 1: Tree Based Models using College Data

Partition into training and testing set

```
# Read in dataset
college <- read.csv("College.csv")

# Remove NAs
college <- na.omit(college)

# Set seed for reproducibility
set.seed(299)

# Split data into training and testing data
data_split_college <- initial_split(college, prop = 0.8)

# Extract the training and test data, removing college ID column
training_data_college <- training(data_split_college) %>% select(-College)
testing_data_college <- testing(data_split_college) %>% select(-College)
```

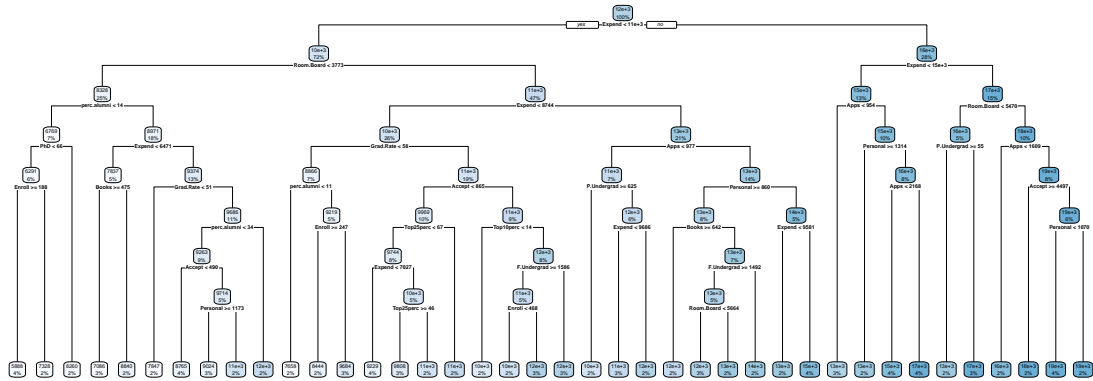
a) Build a regression tree on training data

In order to implement the CART approach implementing recursive partitioning and pruning, I first fit a regression tree using $cp=0$ (complexity parameter). This parameter controls the complexity pruning in the CART algorithm, i.e., how splits are undertaken. Setting $cp=0$ was a safe choice to ensure that the tree was sufficiently large, allowing all potential splits are considered. I also produced a plot of this tree.

```
# Set seed for reproducibility
set.seed(299)

# Fit initial tree:
initial.tree.fit <- rpart(Outstate ~ .,
                          data = training_data_college,
                          control = rpart.control(cp = 0))

# Tree plot
rpart.plot(initial.tree.fit)
```

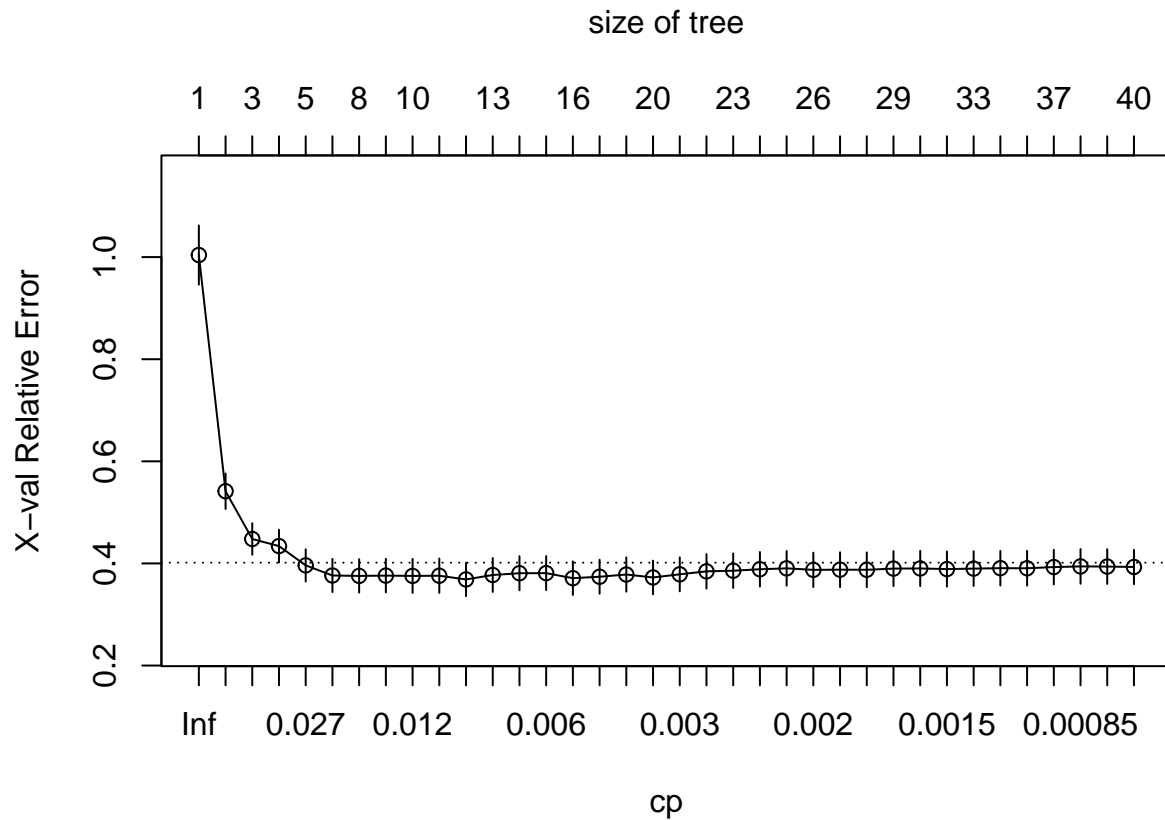


```
# Print and plot the cp table
printcp(initial.tree.fit)
```

```
##
## Regression tree:
## rpart(formula = Outstate ~ ., data = training_data_college, control = rpart.control(cp = 0))
##
## Variables actually used in tree construction:
## [1] Accept      Apps      Books      Enroll      Expend      F.Undergrad
## [7] Grad.Rate  P.Undergrad perc.alumni Personal      PhD          Room.Board
## [13] Top10perc  Top25perc
##
## Root node error: 6222135701/452 = 13765787
##
## n= 452
##
##      CP nsplit rel error  xerror   xstd
## 1  0.49965968      0  1.00000 1.00404 0.058031
## 2  0.10266905      1  0.50034 0.54145 0.034753
## 3  0.05071124      2  0.39767 0.44785 0.030837
## 4  0.04021488      3  0.34696 0.43401 0.032119
## 5  0.01820952      4  0.30675 0.39616 0.031612
## 6  0.01319074      5  0.28854 0.37639 0.032586
## 7  0.01255106      7  0.26215 0.37556 0.032802
## 8  0.01194445      8  0.24960 0.37611 0.032884
```

## 9	0.01165684	9	0.23766	0.37553	0.033331
## 10	0.00942611	10	0.22600	0.37590	0.033641
## 11	0.00770392	11	0.21658	0.36867	0.032816
## 12	0.00672841	12	0.20887	0.37730	0.033123
## 13	0.00619338	13	0.20214	0.38085	0.033378
## 14	0.00587852	14	0.19595	0.38098	0.033357
## 15	0.00538113	15	0.19007	0.37111	0.032927
## 16	0.00531018	17	0.17931	0.37395	0.033274
## 17	0.00377286	18	0.17400	0.37834	0.033610
## 18	0.00353985	19	0.17023	0.37250	0.032941
## 19	0.00254368	20	0.16669	0.37870	0.033291
## 20	0.00246805	21	0.16414	0.38447	0.033757
## 21	0.00212300	22	0.16167	0.38576	0.033736
## 22	0.00210237	23	0.15955	0.38858	0.033838
## 23	0.00207706	24	0.15745	0.39037	0.033877
## 24	0.00199280	25	0.15537	0.38740	0.033677
## 25	0.00188271	26	0.15338	0.38777	0.034094
## 26	0.00187160	27	0.15150	0.38754	0.034083
## 27	0.00179477	28	0.14963	0.38986	0.034280
## 28	0.00167899	30	0.14604	0.39016	0.034537
## 29	0.00139108	31	0.14436	0.38893	0.034479
## 30	0.00120513	32	0.14297	0.38988	0.033974
## 31	0.00119267	33	0.14176	0.39068	0.033937
## 32	0.00110541	34	0.14057	0.39051	0.033940
## 33	0.00099926	36	0.13836	0.39288	0.033968
## 34	0.00073074	37	0.13736	0.39417	0.033983
## 35	0.00031851	38	0.13663	0.39388	0.033991
## 36	0.00000000	39	0.13631	0.39305	0.033715

```
plotcp(initial.tree.fit)
```

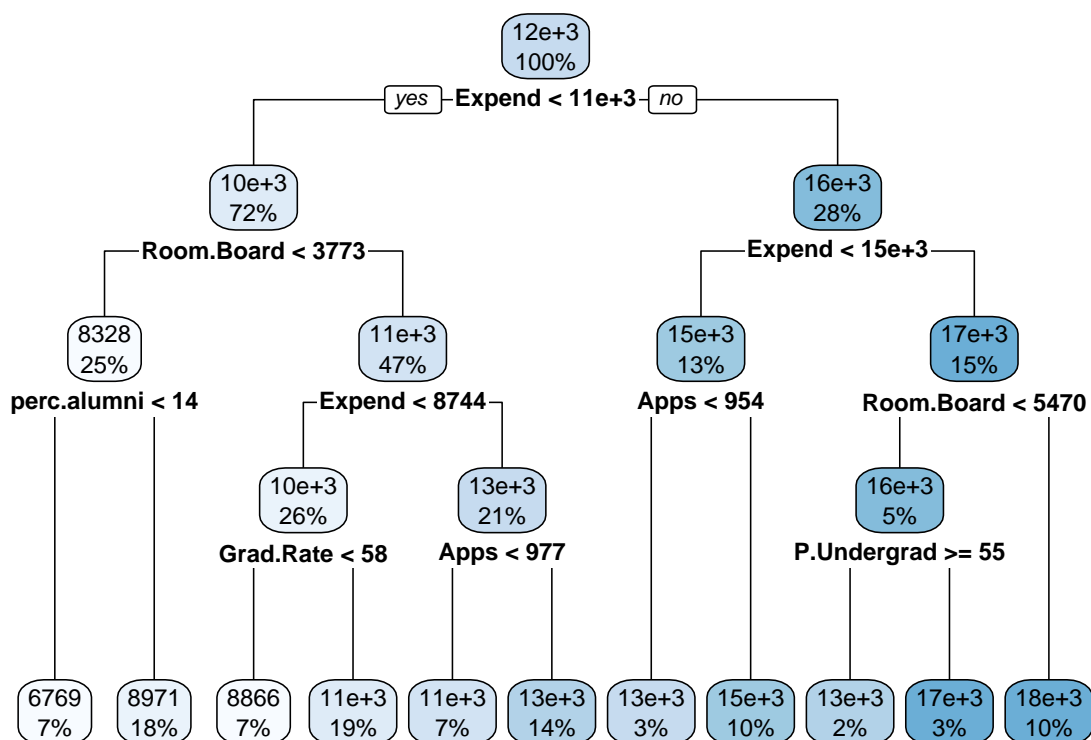


To explore the impact of adjusting the complexity parameter, I also fit a second model setting $cp=0.01$. This model had fewer splits by comparison. When plotted, this tree was noticeably smaller than the previous tree.

```
# Set seed for reproducibility
set.seed(299)

# Fit another tree:
tree.fit.2 <- rpart(Outstate ~ .,
  data = training_data_college,
  control = rpart.control(cp = 0.01))

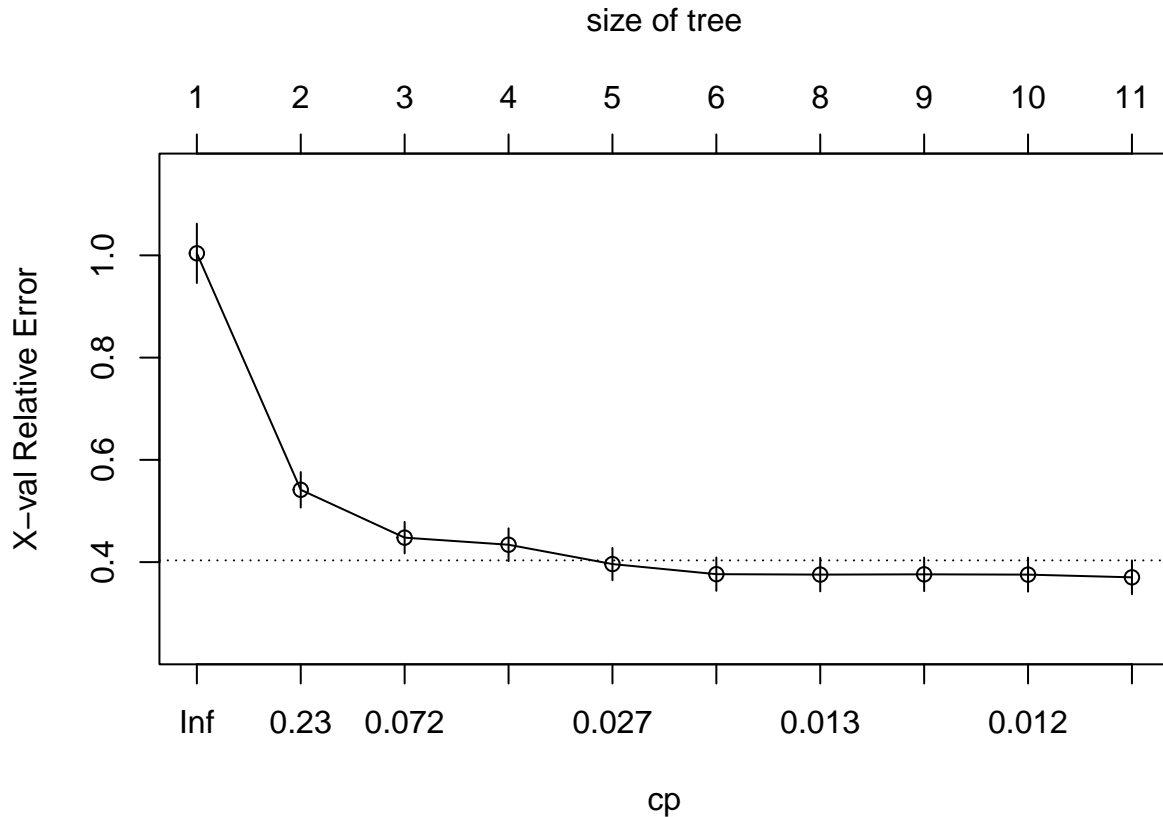
# Tree plot
rpart.plot(tree.fit.2)
```



```
# Print and plot the cp table
printcp(tree.fit.2)
```

```
##
## Regression tree:
## rpart(formula = Outstate ~ ., data = training_data_college, control = rpart.control(cp = 0.01))
##
## Variables actually used in tree construction:
## [1] Apps      Expend      Grad.Rate  P.Undergrad perc.alumni Room.Board
##
## Root node error: 6222135701/452 = 13765787
##
## n= 452
##
##      CP nsplit rel error  xerror   xstd
## 1  0.499660      0  1.00000 1.00404 0.058031
## 2  0.102669      1  0.50034 0.54145 0.034753
## 3  0.050711      2  0.39767 0.44785 0.030837
## 4  0.040215      3  0.34696 0.43401 0.032119
## 5  0.018210      4  0.30675 0.39616 0.031612
## 6  0.013191      5  0.28854 0.37639 0.032586
## 7  0.012551      7  0.26215 0.37556 0.032802
## 8  0.011944      8  0.24960 0.37611 0.032884
## 9  0.011657      9  0.23766 0.37553 0.033331
## 10 0.010000     10  0.22600 0.37024 0.033137
```

```
plotcp(tree.fit.2)
```



Importantly, setting $cp=0$ is the preferred choice, as it allowed for a large enough tree to be grown for the cost complexity table. In the $cp = 0.01$ model, the smallest error (scaled cross-validation error) was 0.37369, whereas the $cp = 0$ model achieved a slightly lower minimum error of 0.36867. This shows us that a fully grown tree in this case is better suited for selecting an optimal complexity parameter based on cross-validation.

The optimal tree selected from the $cp = 0$ model has a **complexity parameter of 0.00770392**, with **11 splits** (i.e., 12 terminal nodes). This was the model that minimised scaled cross-validation error (**xerror = 0.36867**). Therefore, this was chosen as the final pruned tree.

b) Perform random forest on training data

I decided to explore two tuning grids to find the optimal random forest model using cross-validation RMSE. The `mtry` parameter controls the number of predictors randomly selected at each split in the forest. I decided to tune `mtry` over the full range of possible values, from 1 to 16 (i.e., the full number of predictors in the college dataset).

For the first grid (`min.node.size = 1:7`), the best model had `mtry = 7` and `min.node.size = 5`.

```
# Set seed for reproducibility
set.seed(299)

# Set cross-validation
ctrl <- trainControl(method = "cv",
```

```

summaryFunction = defaultSummary)

# Define grid for tuning mtry and min.node.size
rf.grid <- expand.grid(
  mtry = 1:16, # max no. of predictors
  splitrule = "variance",
  min.node.size = c(1:7)
)

# Fit random forest using ranger via caret
rf.fit <- train(
  Outstate ~ .,
  data = training_data_college,
  method = "ranger",
  tuneGrid = rf.grid,
  trControl = ctrl
)

# Obtain optimal tuning parameters from cross-validation
rf.fit$bestTune # mtry = 7, min.node.size = 5

##      mtry splitrule min.node.size
## 47      7  variance                5

```

```
ggplot(rf.fit, highlight = TRUE)
```

```

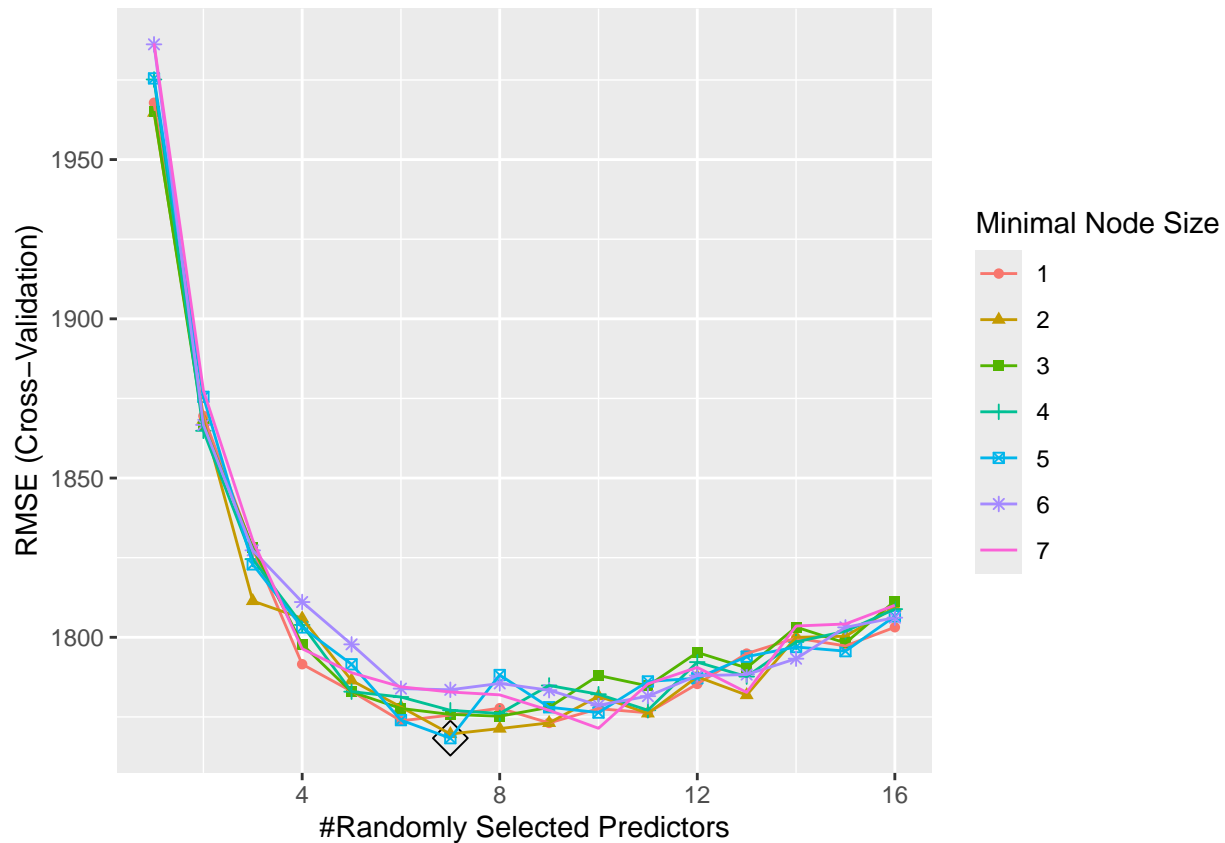
## Warning: The shape palette can deal with a maximum of 6 discrete values because more
## than 6 becomes difficult to discriminate
## i you have requested 7 values. Consider specifying shapes manually if you need
## that many have them.

```

```

## Warning: Removed 16 rows containing missing values or values outside the scale range
## (`geom_point()`).

```

I then decided to try an expanded grid range for min.node.size, extending it to 1:10 to check for any better performing values beyond the original range.

```
# Set seed for reproducibility
set.seed(299)

# Define another grid for tuning mtry and min.node.size
rf.grid2 <- expand.grid(
  mtry = 1:16, # max no. of predictors
  splitrule = "variance",
  min.node.size = c(1:10)
)

# Fit random forest using ranger via caret
rf.fit2 <- train(
  Outstate ~ .,
  data = training_data_college,
  method = "ranger",
  tuneGrid = rf.grid2,
  trControl = ctrl
)

# Optimal parameters
rf.fit2$bestTune # mtry = 9, min.node.size = 3 (row 83)
```

```
##      mtry splitrule min.node.size
```

```
## 83      9  variance                3
```

```
rf.fit2$results[83, ] # pulling the lowest RMSE: 1763.865
```

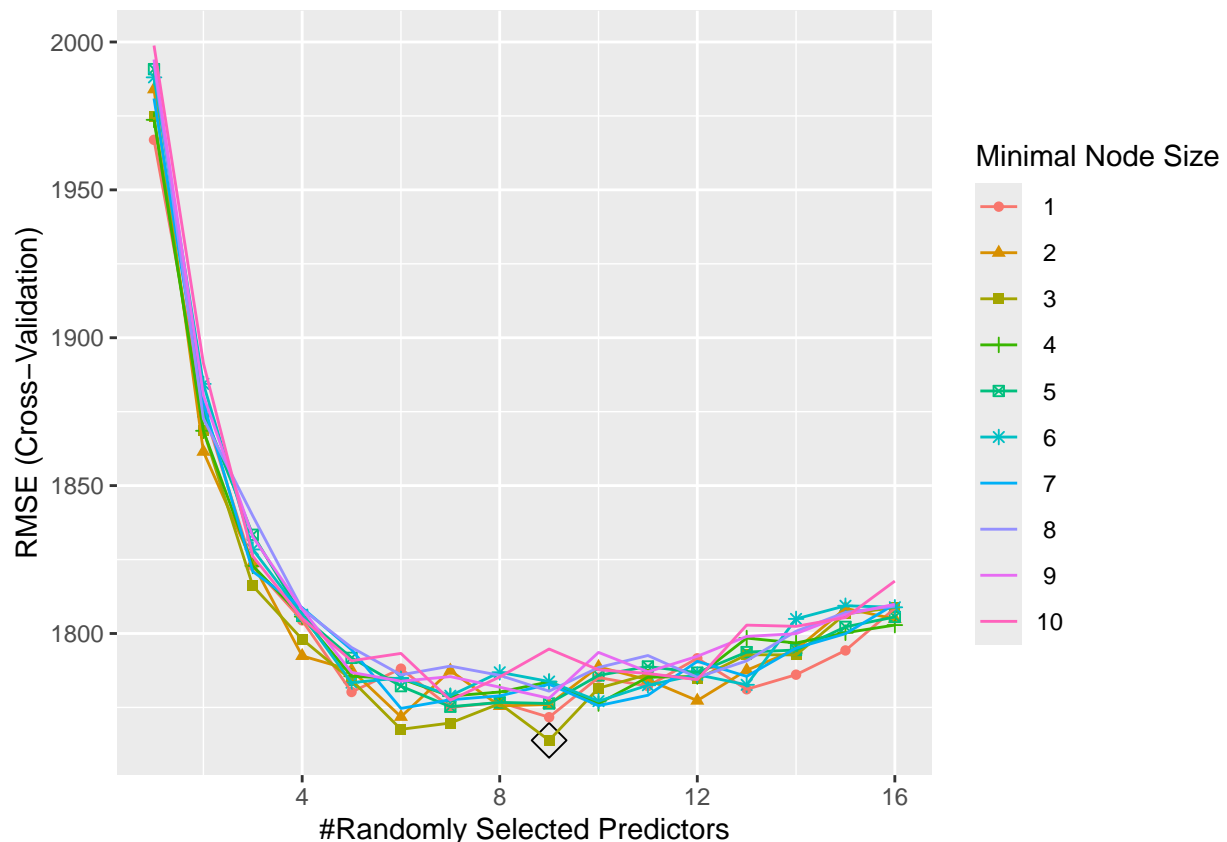
```
##      mtry splitrule min.node.size      RMSE Rsquared      MAE      RMSESD RsquaredSD
## 83      9  variance                3 1763.865 0.774242 1332.22 307.1101 0.08056556
##      MAESD
## 83 176.1794
```

```
# Plot performance for tuning grid values
```

```
ggplot(rf.fit2, highlight = TRUE)
```

```
## Warning: The shape palette can deal with a maximum of 6 discrete values because more
## than 6 becomes difficult to discriminate
## i you have requested 10 values. Consider specifying shapes manually if you need
## that many have them.
```

```
## Warning: Removed 64 rows containing missing values or values outside the scale range
## (`geom_point()`).
```



From this grid, the optimal tuning parameters were `mtry = 9` and `min.node.size = 3`, selected based on the lowest cross validation RMSE (1763.865). The corresponding plot shows the lowest RMSE.

Next, reporting the variable importance and the test error for this selected model (`rf.fit2`):

I first examined **permutation-based variable importance** in the dataset.

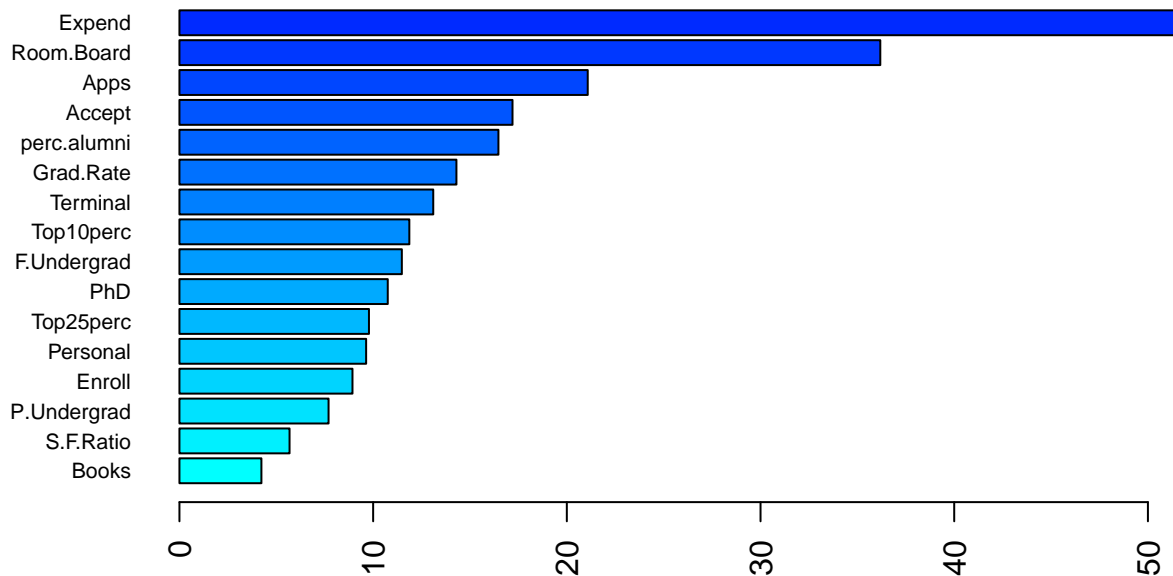
```

# Set seed for reproducibility
set.seed(299)

# Fit random forest using ranger via caret
rf.fit2.per <- ranger(
  Outstate ~ .,
  data = training_data_college,
  mtry = rf.fit2$bestTune$mtry, # selecting the cross-validated parameter
  min.node.size = rf.fit2$bestTune$min.node.size, # selecting the cross-validated parameter
  splitrule = "variance",
  importance = "permutation", # selecting permutation
  scale.permutation.importance = TRUE
)

# Plotting the variable importance
barplot(sort(ranger::importance(rf.fit2.per), decreasing = FALSE),
  las = 2, horiz = TRUE, cex.names = 0.7,
  col = colorRampPalette(colors = c("cyan", "blue"))(19))

```



Based on this plot, **Expend** appears to have the highest variable importance, followed by **Room Board** and **Apps**, respectively. **Books** appears to be the least important variable, by comparison, followed by **S.F. Ratio** and **P.Undergrad**, in that order.

I decided to explore variable importance using the impurity method for the same model.

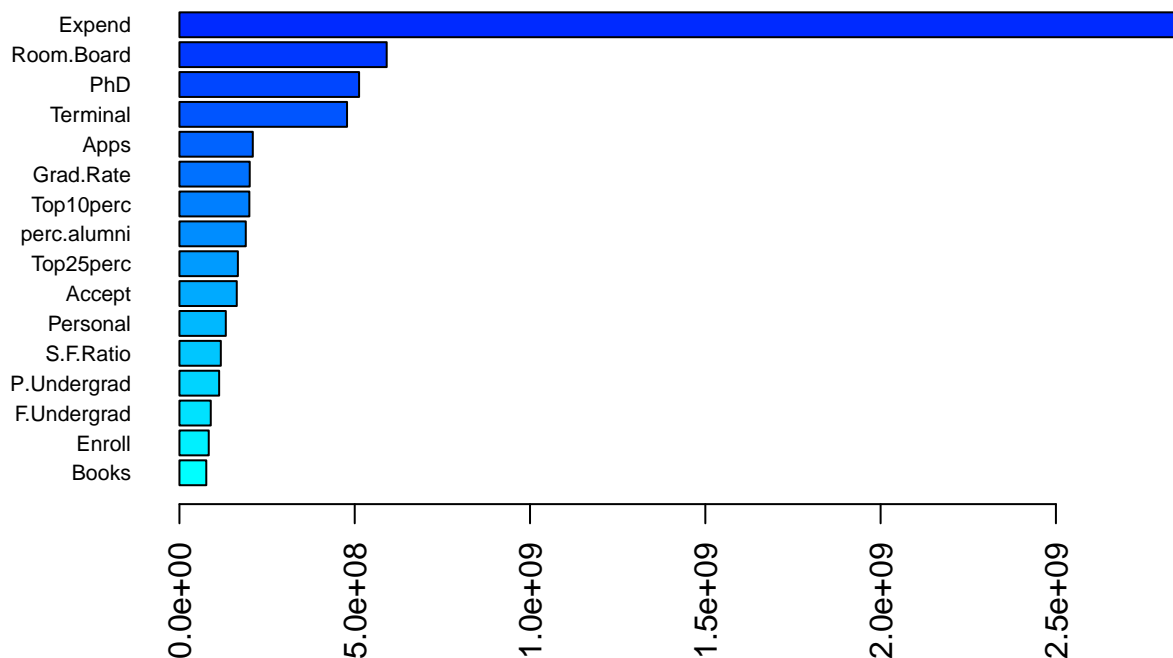
```

# Set seed for reproducibility
set.seed(299)

# Fit random forest using ranger via caret
rf.fit2.imp <- ranger(
  Outstate ~ .,
  data = training_data_college,
  mtry = rf.fit2$bestTune$mtry, # selecting the cross-validated parameter
  min.node.size = rf.fit2$bestTune$min.node.size, # selecting the cross-validated parameter
  splitrule = "variance",
  importance = "impurity", # selecting impurity
  scale.permutation.importance = TRUE
)

# Plotting the variable importance
barplot(sort(ranger::importance(rf.fit2.imp), decreasing = FALSE),
  las = 2, horiz = TRUE, cex.names = 0.7,
  col = colorRampPalette(colors = c("cyan", "blue"))(19))

```



As with the permutation method, the most important variable based on this plot appears to be **Expend**, followed by **Room.Board**. However, the impurity method shows that **PhD** is the third most important variable, which is different to what was identified using the permutation method (the permutation method identified the third most important variable as **Apps**).

Books appears to be the least important variable using the impurity method, similar to the permutation method. However, unlike the permutation method, the subsequent least important variables are **Enroll** and

F.Undergrad, in that order. This difference is consistent with the literature, with permutation importance avoiding biases that affect impurity measures, though impurity based variable importance rankings can be more computationally efficient and sometimes more robust to data perturbations in high-dimensional settings (Nembrini, et al., 2018).

Next, finding the **test error of the model**:

```
# Set seed for reproducibility
set.seed(299)

# Predict on the test data
pred.rf2 <- predict(rf.fit2, newdata = testing_data_college)

# RMSE based on the test data
rf_test_rmse <- RMSE(pred.rf2, testing_data_college$Outstate)

# Test error
rf_test_rmse
```

```
## [1] 1629.167
```

Therefore, the **test error (RMSE)** is **1629.167**.

c) Perform boosting on training data

I proceeded to fit a gradient boosting model with the Gaussian loss function.

```
# Set seed for reproducibility
set.seed(299)

# Initial grid for tuning
# gbm.grid <- expand.grid(
#   n.trees = c(100, 200, 500, 1000, 2000, 5000, 10000),
#   interaction.depth = 1:3, # we want to learn slowly, so keep small
#   shrinkage = c(0.005, 0.01, 0.05), # range of lambda values
#   n.minobsinnode = 10 # Based on notes, this can be fixed
#)

# Fit the GBM model
# gbm.fit <- train(
#   Outstate ~ .,
#   data = training_data_college,
#   method = "gbm",
#   tuneGrid = gbm.grid,
#   trControl = ctrl,
#   verbose = FALSE
#)

# View best tuning parameters
# gbm.fit$bestTune
# n trees = 2000; interaction.depth=3; shrinkage=0.005; n.minobsinnode=10
```

```

# Define grid for tuning
gbm.grid <- expand.grid(
  n.trees = c(100, 200, 500, 1000, 2000, 5000, 10000),
  interaction.depth = 1:4, # increase to 4, still keeping small
  shrinkage = c(0.001, 0.005, 0.01, 0.05), # adding an additional shrinkage
  n.minobsinnode = 10
)

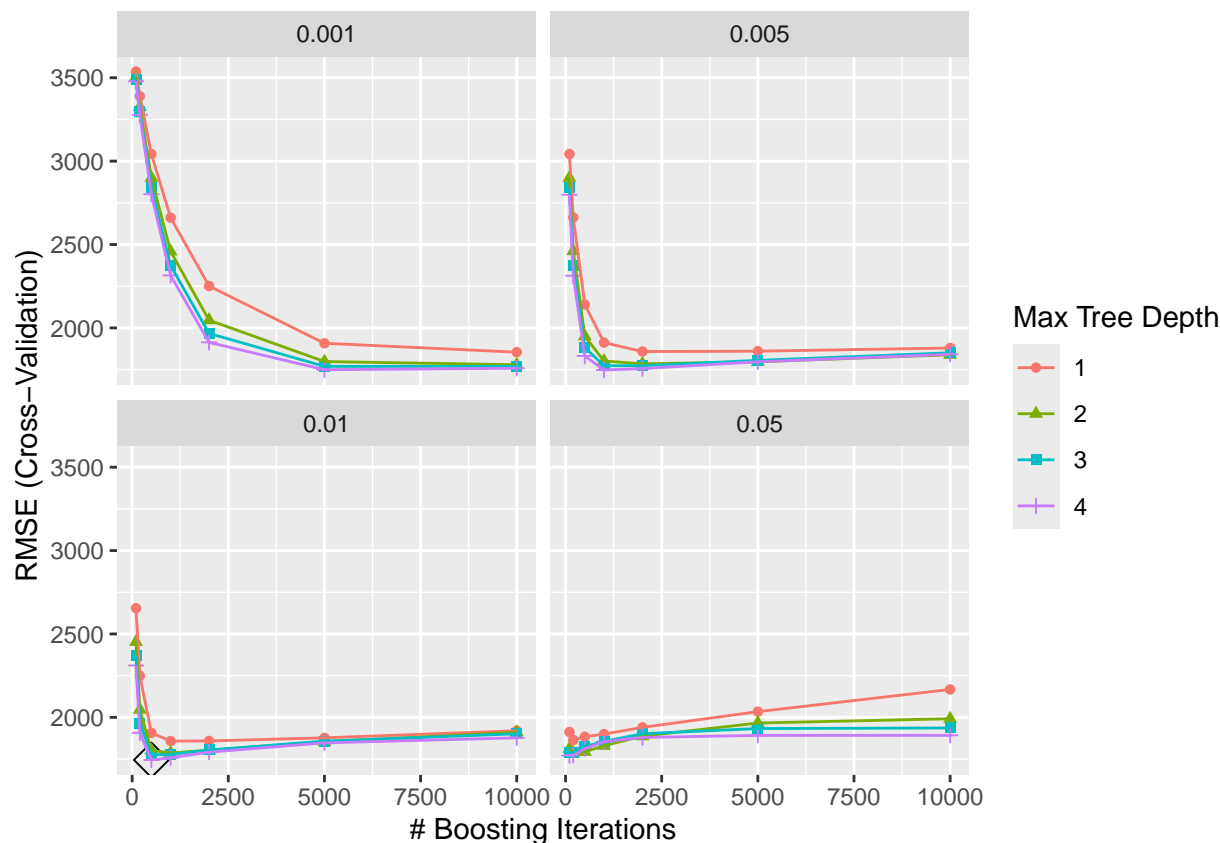
# Fit the GBM model
gbm.fit <- train(
  Outstate ~ .,
  data = training_data_college,
  method = "gbm",
  tuneGrid = gbm.grid,
  trControl = ctrl,
  verbose = FALSE
)

# View best tuning parameters
gbm.fit$bestTune # n.trees = 500; shrinkage=0.01, interaction.depth=4

##      n.trees interaction.depth shrinkage n.minobsinnode
## 80         500                4      0.01             10

# Plot the CV results
ggplot(gbm.fit, highlight = TRUE)

```



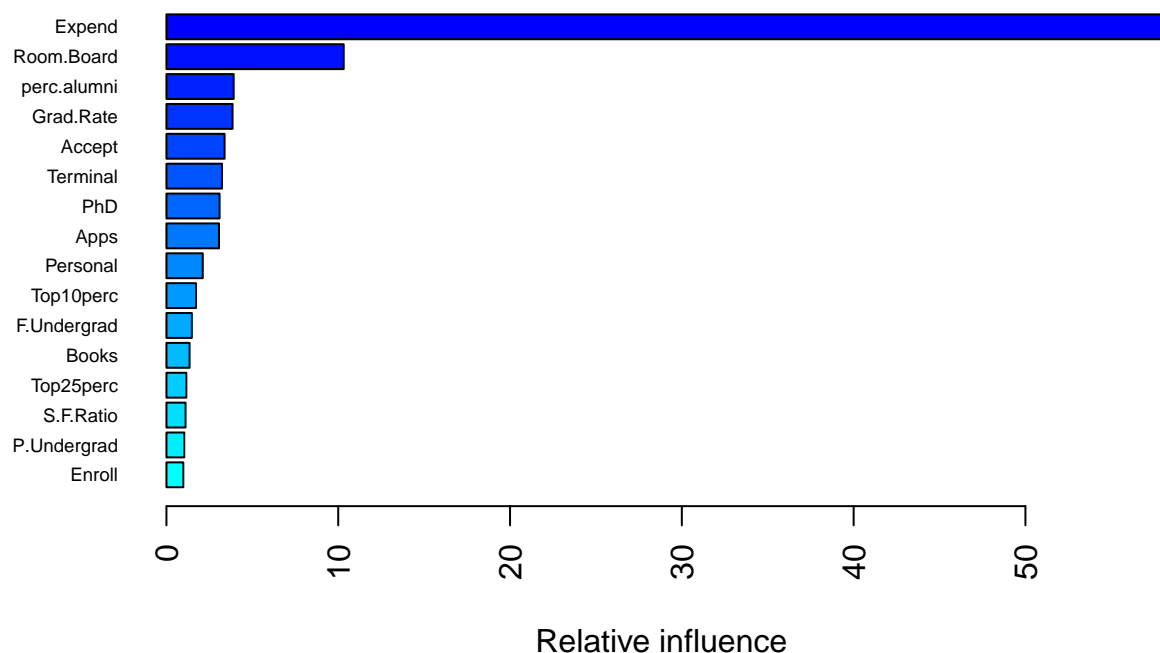
I initially tested a smaller grid when tuning the model parameters with `interaction.depth = 1:3`. The best model had `interaction.depth = 3`, which was the upper limit of that range. Even though it is acceptable for `interaction.depth` to be at the boundary, I decided to expand the grid to 1:4 to explore other ranges and to also explore another shrinkage parameter.

Based on the cross-validation RMSE plot showing the combinations of shrinkage (i.e., the learning rate), `n.trees` (number of boosting iterations), and interaction depth (tree depth), we can see that the lowest RMSE was achieved with **shrinkage = 0.01**, **n.minobsinnode = 10**, **interaction.depth = 4**, and approximately **500 boosting iterations (n.trees)**. This is consistent with the Generalized Boosting Models package documentation, which notes that the relationship between shrinkage and optimal iterations is roughly proportional, as our optimal `n.trees` decreased when we increased the shrinkage value (Ridgeway, 2024). Notably, while `n.minobsinnode` was at the boundary of the range, it was noted by the Professor that this is acceptable.

Next, finding the **variable importance**.

```
# Set seed for reproducibility
set.seed(299)

# Using summary to find variable importance for boosting
summary(gbm.fit$finalModel, las = 2, cBars = 19, cex.names = 0.6)
```



```
##           var      rel.inf
## Expend      Expend 58.2031691
## Room.Board  Room.Board 10.3174922
## perc.alumni perc.alumni 3.9127298
## Grad.Rate   Grad.Rate 3.8474112
## Accept      Accept 3.3836026
## Terminal    Terminal 3.2318329
## PhD         PhD 3.0933115
## Apps        Apps 3.0597074
## Personal    Personal 2.1141994
## Top10perc   Top10perc 1.7216327
## F.Undergrad F.Undergrad 1.4781997
## Books       Books 1.3455640
## Top25perc   Top25perc 1.1584877
## S.F.Ratio   S.F.Ratio 1.1122809
## P.Undergrad P.Undergrad 1.0374312
## Enroll      Enroll 0.9829476
```

From this, we can see the most important predictor appears to be **Expend**, followed by Room.Board and perc.alumni, respectively. The least important variable based on this summary of the boosting model appears to be Enroll, followed by P.Undergrad and S.F. Ratio, in that order.

Next, finding the **test error** for the boosting model:


```

# Set seed for reproducibility
set.seed(299)

# Predict on the test data
pred.gbm.fit <- predict(gbm.fit, newdata = testing_data_college)

# RMSE based on the test data
gbm_test_rmse <- RMSE(pred.gbm.fit, testing_data_college$Outstate)

# Test error
gbm_test_rmse

```

```
## [1] 1568.585
```

The test error for the model is **1568.585**.

Part 2: Classification using Auto dataset

Partition into training and testing set

```

# Read in dataset
auto <- read.csv("auto.csv")

# Remove NAs
auto <- na.omit(auto)

# Make sure factor variables are correctly coded
auto$cylinders <- factor(auto$cylinders)
auto$origin <- factor(auto$origin)
auto$mpg_cat <- factor(auto$mpg_cat, levels = c("low", "high"))

# Check variable types
str(auto)

```

```

## 'data.frame':   392 obs. of  8 variables:
## $ cylinders   : Factor w/ 5 levels "3","4","5","6",...: 5 5 5 5 5 5 5 5 5 5 ...
## $ displacement: num  307 350 318 304 302 429 454 440 455 390 ...
## $ horsepower  : int   130 165 150 150 140 198 220 215 225 190 ...
## $ weight       : int  3504 3693 3436 3433 3449 4341 4354 4312 4425 3850 ...
## $ acceleration: num   12 11.5 11 12 10.5 10 9 8.5 10 8.5 ...
## $ year         : int   70 70 70 70 70 70 70 70 70 70 ...
## $ origin       : Factor w/ 3 levels "1","2","3": 1 1 1 1 1 1 1 1 1 1 ...
## $ mpg_cat      : Factor w/ 2 levels "low","high": 1 1 1 1 1 1 1 1 1 1 ...

```

```
levels(auto$mpg_cat)
```

```
## [1] "low" "high"
```

```

# Set seed for reproducibility
set.seed(299)

# Split data into training and testing data
data_split_auto <- initial_split(auto, prop = 0.7)

# Extract the training and test data
training_data_auto <- training(data_split_auto)
testing_data_auto <- testing(data_split_auto)

# Check variable types
# str(training_data_auto)
# str(testing_data_auto)

```

I made sure to recode the variables origin and cylinders to factor variable type. Although cylinders was originally represented as an integer, it is a multi-valued discrete variable as its values represent categorical groupings of engine types (i.e., 4, 6, 8 cylinder),

a) Classification Tree

Using the rpart method, I proceeded to fit the tree:

```

# Set seed for reproducibility
set.seed(299)

# Build tree
rpart.class.tree.fit <- rpart(formula = mpg_cat ~ . ,
                              data = training_data_auto,
                              control = rpart.control(cp = 0))

# Produce cp table and plot tree
cpTable <- printcp(rpart.class.tree.fit)

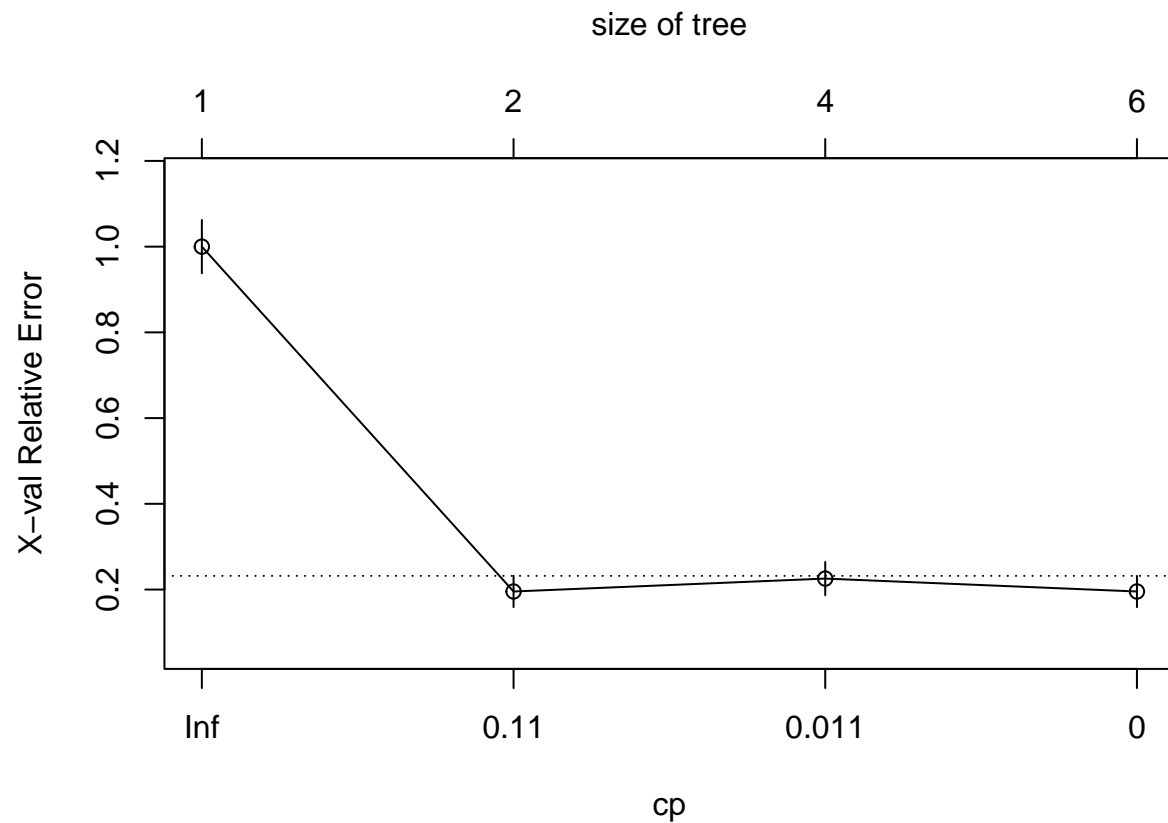
```

```

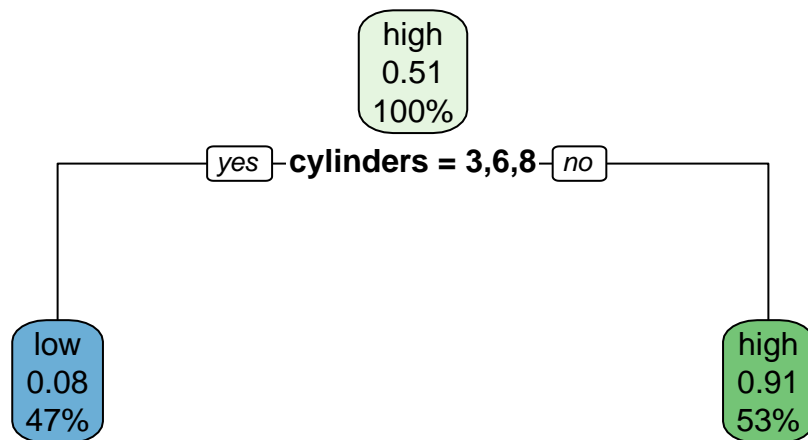
##
## Classification tree:
## rpart(formula = mpg_cat ~ ., data = training_data_auto, control = rpart.control(cp = 0))
##
## Variables actually used in tree construction:
## [1] cylinders    displacement horsepower    year
##
## Root node error: 133/274 = 0.4854
##
## n= 274
##
##          CP nsplit rel error  xerror    xstd
## 1 0.8270677      0   1.00000 1.00000 0.062203
## 2 0.0150376      1   0.17293 0.19549 0.036474
## 3 0.0075188      3   0.14286 0.22556 0.038862
## 4 0.0000000      5   0.12782 0.19549 0.036474

```

```
plotcp(rpart.class.tree.fit)
```



```
# Obtain cp with minimum xerror  
minErr <- which.min(cpTable[, "xerror"])  
  
# Prune the tree using best cp  
pruned.tree <- prune(rpart.class.tree.fit, cp = cpTable[minErr, "CP"])  
  
# Plot pruned tree  
rpart.plot(pruned.tree)
```



I set `cp=0`, to allow for a sufficiently large enough tree to be grown. From the results, two trees had the same minimum (scaled) cross-validation error (**xerror = 0.19549**). I chose the simpler model **with 1 split** to prioritise interpretability.

Therefore, the optimal tree selected from this `cp = 0` model has a **complexity parameter of 0.0150376**, with **1 split** (i.e, **tree size corresponds to 2 terminal nodes** in the decision tree, as seen in the plot). This was the model that minimised scaled cross-validation error (**xerror = 0.19549**). Therefore, this was chosen as the final pruned tree.

Next, using the 1SE rule to build the tree:

```

# Set seed for reproducibility
set.seed(299)

# Find row with min Cross validation error (xerror)
minErr.1se <- which.min(cpTable[, 4]) # column 4 is xerror

# Extracts the cp parameter corresponding to the 1se rule
tree.fit.1se <- rpart::prune(rpart.class.tree.fit,
                             cp = cpTable[minErr.1se, 1]) # column 1 is cp

# Cp Table and cp plot for the 1se tree
cpTable <- printcp(rpart.class.tree.fit)

```

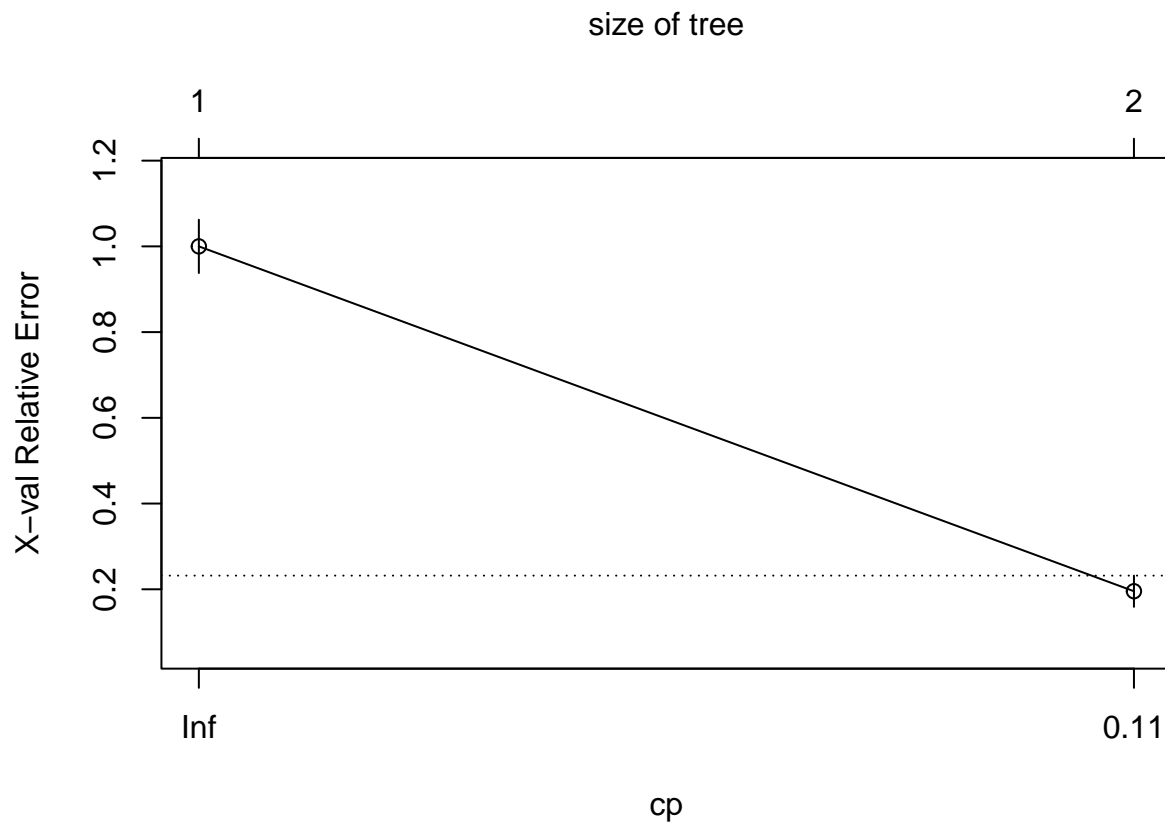
```

##
## Classification tree:

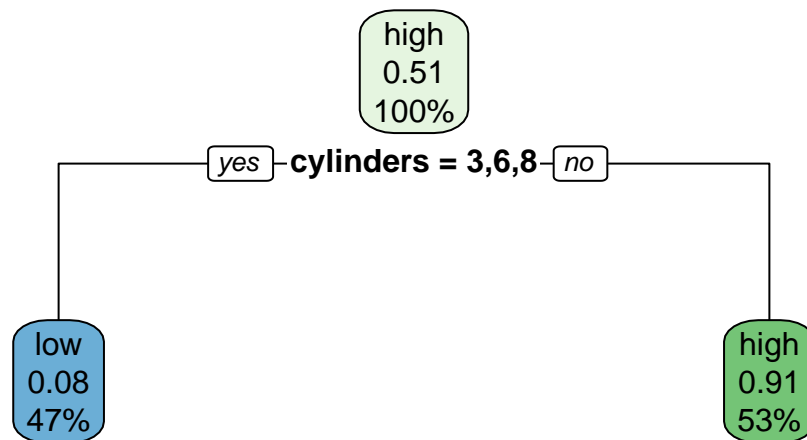
```

```
## rpart(formula = mpg_cat ~ ., data = training_data_auto, control = rpart.control(cp = 0))
##
## Variables actually used in tree construction:
## [1] cylinders    displacement horsepower    year
##
## Root node error: 133/274 = 0.4854
##
## n= 274
##
##      CP nsplit rel error  xerror   xstd
## 1 0.8270677     0  1.00000 1.00000 0.062203
## 2 0.0150376     1  0.17293 0.19549 0.036474
## 3 0.0075188     3  0.14286 0.22556 0.038862
## 4 0.0000000     5  0.12782 0.19549 0.036474
```

```
plotcp(tree.fit.1se)
```



```
# Plot the pruned tree
rpart.plot(tree.fit.1se)
```



In applying the 1se rule, we are looking for the smallest tree below the dotted line. The 1se rule allows us to select the smallest tree whose cross-validation error is within one standard error of the minimum. In this case, the **selected tree has 1 split, with 2 terminal nodes** ($cp=0.0150376$, $xerror=0.19549$). Therefore, the tree selected by the 1SE rule is the same as the one selected by the minimum cross-validation error, and they have the same tree size.

b) Boosting model: AdaBoost

```

# Set seed for reproducibility
set.seed(299)

# Check factor levels
levels(training_data_auto$mpg_cat)

```

```
## [1] "low" "high"
```

```

# Set cross validation
ctrl.adaboost <- trainControl(method = "cv",
                              classProbs = TRUE,
                              summaryFunction = twoClassSummary)

# Tuning grid for adaboost
gbm.ada.grid <- expand.grid(
  n.trees = c(100, 200, 500, 1000, 2000, 5000, 10000),

```

```

interaction.depth = 1:4, # want to learn slowly, so keep small
shrinkage = c(0.001, 0.003, 0.005, 0.01), # range of lambda values
n.minobsinnode = 10 # based on notes, can fix this at 10
)

# Fit gbm with caret, using adaboost
gbm.ada.fit <- train(mpg_cat ~ .,
  data = training_data_auto,
  tuneGrid = gbm.ada.grid,
  trControl = ctrl.adaboost,
  method = "gbm",
  distribution = "adaboost",
  metric = "ROC",
  verbose = FALSE
)

```

```

## Warning in (function (x, y, offset = NULL, misc = NULL, distribution =
## "bernoulli", : variable 2: cylinders5 has no variation.

```

```

## Warning in (function (x, y, offset = NULL, misc = NULL, distribution =
## "bernoulli", : variable 2: cylinders5 has no variation.

```

```

## Warning in (function (x, y, offset = NULL, misc = NULL, distribution =
## "bernoulli", : variable 2: cylinders5 has no variation.

```

```

## Warning in (function (x, y, offset = NULL, misc = NULL, distribution =
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## "bernoulli", : variable 2: cylinders5 has no variation.

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## "bernoulli", : variable 2: cylinders5 has no variation.

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## "bernoulli", : variable 2: cylinders5 has no variation.

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```

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## Warning in (function (x, y, offset = NULL, misc = NULL, distribution =
## "bernoulli", : variable 2: cylinders5 has no variation.

```

```

## Warning in (function (x, y, offset = NULL, misc = NULL, distribution =
## "bernoulli", : variable 2: cylinders5 has no variation.

```

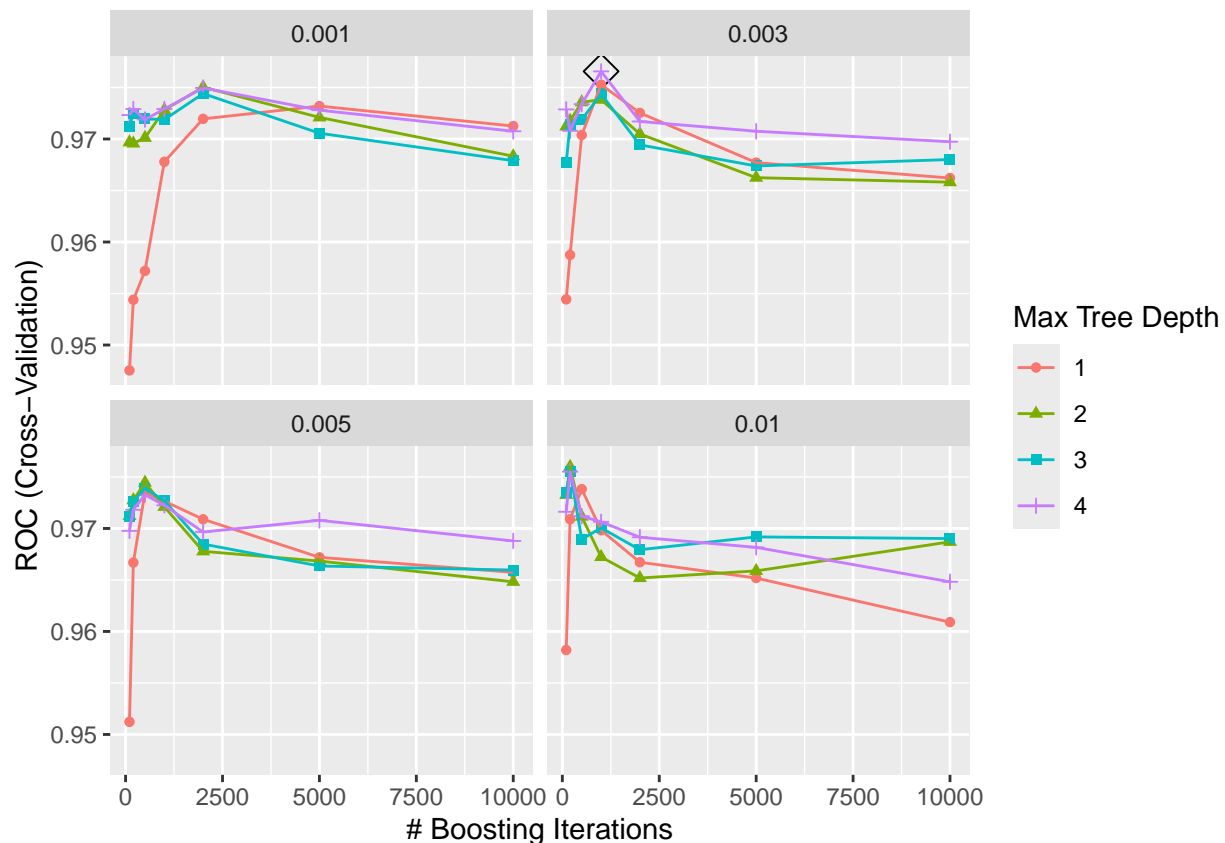
```
## Warning in (function (x, y, offset = NULL, misc = NULL, distribution =
## "bernoulli", : variable 2: cylinders5 has no variation.
```

```
## Warning in (function (x, y, offset = NULL, misc = NULL, distribution =
## "bernoulli", : variable 2: cylinders5 has no variation.
```

```
## Warning in (function (x, y, offset = NULL, misc = NULL, distribution =
## "bernoulli", : variable 2: cylinders5 has no variation.
```

```
## Warning in (function (x, y, offset = NULL, misc = NULL, distribution =
## "bernoulli", : variable 2: cylinders5 has no variation.
```

```
# Plot to show best tuning parameters
ggplot(gbm.ada.fit, highlight = TRUE)
```



```
# Optimal tuning parameters
gbm.ada.fit$bestTune
```

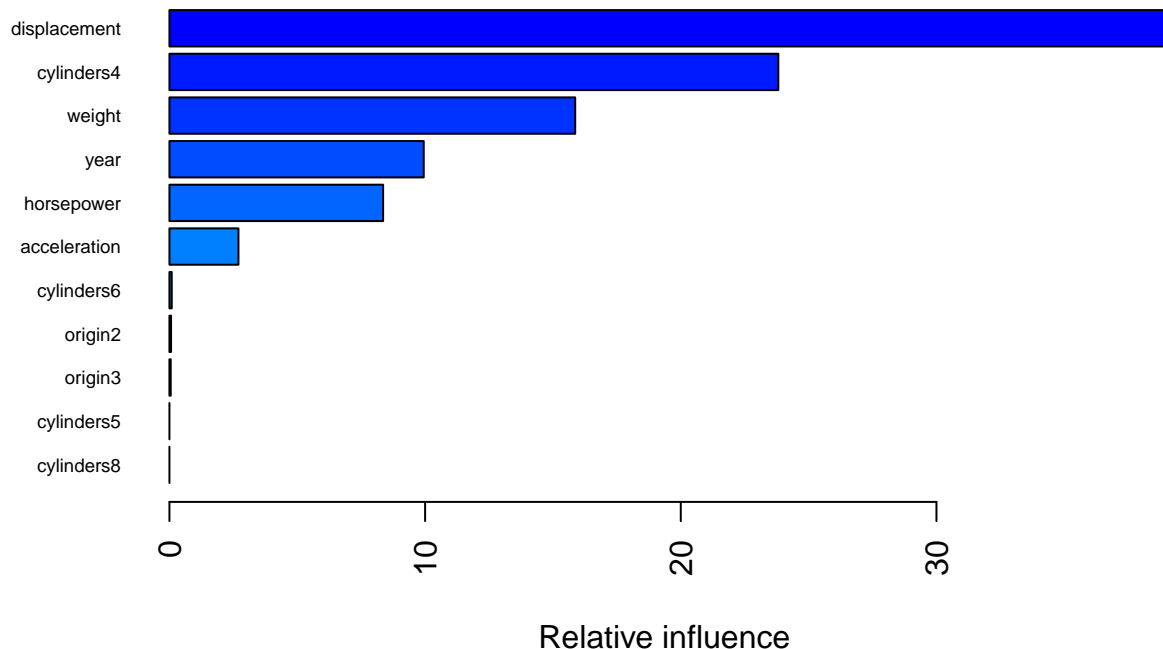
```
##      n.trees interaction.depth shrinkage n.minobsinnode
## 53      1000                4      0.003             10
```

I ensured the outcome variable mpg_cat was coded so that high was the second factor level, in order for it to be treated as the positive class when computing AUC using caret.

I then proceeded to perform boosting using adaboost. I initially tried a range of values for interaction depth between 1:5, however, this produced a shrinkage value at the boundary of the grid (0.01). I then tuned the grid keeping interaction.depth at 4, which was appropriate as it gave me n.trees and shrinkage values not at the boundary of their respective grids. Based on this model, the optimal tuning parameters were **n.trees = 1000, interaction.depth = 4, shrinkage = 0.003, and n.minobsinnode = 10**, based on 10 fold cross validation AUC. This is evident based on the plot, where we can see the best performance at shrinkage=0.003 and interaction.depth=4.

```
# Set seed for reproducibility
set.seed(299)

# Presenting variable importance
summary(gbm.ada.fit$finalModel, las = 2, cBars = 19, cex.names = 0.6)
```



```
##           var      rel.inf
## displacement displacement 39.10985195
## cylinders4    cylinders4 23.81490930
## weight        weight 15.87002938
## year          year  9.94579628
## horsepower    horsepower 8.35779533
## acceleration  acceleration 2.69886152
## cylinders6    cylinders6 0.08945314
## origin2       origin2 0.06273843
## origin3       origin3 0.05056466
## cylinders5    cylinders5 0.00000000
## cylinders8    cylinders8 0.00000000
```

From this, we can see the most important predictor appears to be **displacement**, followed by **cylinders4** and **weight**, respectively. The least important variable based on this model appears to be **cylinders8**, followed by **cylinders5** and **origin3**, in that order.

Next, obtaining test error:

```
# Set seed for reproducibility
set.seed(299)

# Predict probabilities for positive class (ie high)
gbmA.prob <- predict(gbm.ada.fit, newdata = testing_data_auto, type = "prob")[, "high"]

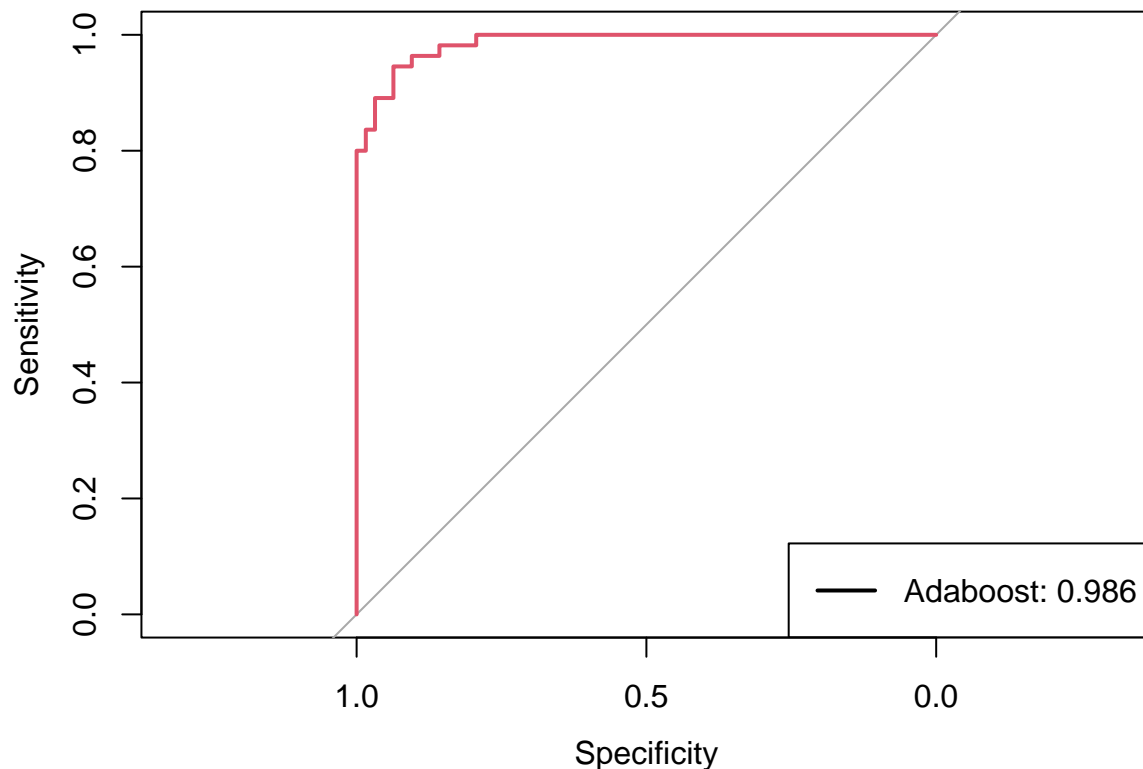
# Compute and plot ROC
roc.gbmA <- roc(testing_data_auto$mpg_cat, gbmA.prob)
```

```
## Setting levels: control = low, case = high
```

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

```
plot(roc.gbmA, col = 2)

# Test AUC
auc <- roc.gbmA$auc[1]
modelName <- "Adaboost"
legend("bottomright", legend = paste0(modelName, ": ", round(auc,3)),
col = 1:2, lwd = 2)
```



To find the test performance for this model, I computed the AUC (area under the ROC curve). Based on the plot, **AUC was 0.986**, which represents excellent classification performance for predicting mpg_cat on the test set. This would indicate that the adaboost model is fairly reliable in distinguishing between high and low fuel efficiency.

References

Ridgeway, G. (2024, June 26). Generalized Boosted Models: A guide to the gbm package.

Nembrini, S., König, I. R., & Wright, M. N. (2018). The revival of the Gini importance?. *Bioinformatics*, 34(21), 3711-3718.