CS 189 Homework5

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July 29, 2019

I certify that all solutions are entirely in my own words and that I have not looked at another student's solutions. I have given credit to all external sources I consulted.

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Contents

1 Decision Trees for Classification

1.1 Implement Decision Trees

```
class Node:
    def __init__(self, left=None, right=None,
        label=None,feature=None,thresh=None):
        self.left = left
        self.right = right
        self.label = label
        self.feature = feature
        self.thresh = thresh

class DecisionTree:

    def __init__(self,max_depth = 10):
        self.max_depth = max_depth

    def entropy(self,y):
        _, counts = np.unique(y, return_counts=True)
        entropy_ = stats.entropy(counts, base=2)
        return entropy_

    def information_gain(self,y,left,right):

        entropy0 = self.entropy(y)
        Sl = len(left)
        Sr = len(right)
        entropy1 = (Sl * self.entropy(left) + Sr * self.entropy(right))/(Sl +
            Sr)

        return entropy0 - entropy1

    # split the X and y by idx and thresh
    def split(self,X, y, idx, thresh):
        left_filter = np.where(X[:,idx] < thresh)[0]
        right_filter = np.where(X[:,idx] >= thresh)[0]
        return X[left_filter], y[left_filter], X[right_filter], y[right_filter]

    # return the thresh, info_gain
    def findSplitWithIndex(self,X,y,idx):
        mean = []
        col = sorted(np.unique(X[:,idx]))

        if len(col)==1:
            mean.append(0)

        for i in range(len(col)-1):
            mean.append( (col[i] + col[i+1])/2 )

        thresh = mean[0]
```

```
        info_ = 0
        for i in mean:
            xl,yl,xr,yr = self.split(X,y,idx,i)
            info_gain = self.information_gain(y,yl,yr)

            if info_gain > info_:
                info_ = info_gain
                thresh = i

        return thresh,info_

    # return the idx(figure), thresh
    def segmenter(self,X, y, m = None):
        info_ = 0
        thresh_ = 0
        idx_ = 0

        idxList = np.array(range(X.shape[1]))
        idxList = idxList[np.random.choice(X.shape[1], m,replace=False)]

        for idx in idxList:
            thresh,info_gain = self.findSplitWithIndex(X,y,idx)

            if info_gain > info_:
                info_ = info_gain
                thresh_ = thresh
                idx_ = idx

        return idx_,thresh_

    def fit_tree(self,X,y,depth=0,m=None):
        major_label = Counter(y).most_common(1)[0][0]
        if self.entropy(y)==0 or depth == self.max_depth:
            return Node(label=major_label)

        idx,thresh = self.segmenter(X,y,m=m)
        xl,yl,xr,yr = self.split(X,y,idx,thresh)


        if len(yl) > 0 and len(yr) >0:
            left = self.fit_tree(xl,yl,depth+1,m=m)
            right = self.fit_tree(xr,yr,depth+1,m=m)

            #label = "(" + idx + ")" + "<" + str(thresh)
            return Node(left,right,label=None,feature=idx,thresh=thresh)
        else:
            return Node(label=major_label)

    def fit(self, X, y,m=None):
        if m == None:
            m = X.shape[1]
```

```
        self.header = self.fit_tree(X,y,m=m)

    def predict(self, X):
        node = self.header
        pred = []

        for i in range(X.shape[0]):
            while node.label==None:
                if X[i][node.feature] < node.thresh:
                    node = node.left
                else:
                    node = node.right
            pred.append(node.label)
            node = self.header
        return pred

    def visualizeTree(self):
        return viz_tree(self.header,features)

    # state the splits (i.e., which feature and which value
    # of that feature to split on) your decision tree made
    # to classify it.
    def __repr__(self,x,features,class_names):
        node = self.header
        while node.label==None:
            if x[node.feature] < node.thresh:
                print(features[node.feature], "<", node.thresh)
                node = node.left
            else:
                print(features[node.feature], ">", node.thresh)
                node = node.right

        print("Therefore the was",class_names[node.label])
```

1.2 Implement Random Forests

```
class RandomForest(DecisionTree):

    def __init__(self,B=100,m=6,max_depth = 10):
        self.B = B
        self.m = m
        self.max_depth = max_depth

    def fit(self, X, y):
        self.forest = []
        for i in tqdm_notebook(range(self.B)):
            index = np.random.choice(X.shape[0], X.shape[0] ,replace=True)
            X = X[index]
            y = y[index]
            self.forest.append(self.fit_tree(X,y,m=self.m))


    def predict(self, X):
        preds = []
        for i in range(X.shape[0]):
            pred = []
            for j in range(self.B):
                node = self.forest[j]
                while node.label==None:
                    if X[i][node.feature] < node.thresh:
                        node = node.left
                    else:
                        node = node.right
                pred.append(node.label)
            preds.append(Counter(pred).most_common(1)[0][0])
        return preds
```

1.3 Describe implementation details

1. For the categorical features, I use the one-hot encoding to make it vectorizing and expands the number of columns in data matrix. For the missing value, I use the mean of this column to replace it.

2. My stopping criterion is the entropy equals 0 or reaches the max_depth.

3. In the random forest implementation, at each node I select m features and pick the best split in this m features. For each tree, I use bagging to select n points from the data matrix, where n equals the number of points in the data matrix. When prediction, I choose the most common prediction in B trees.

4. Use vectorizing operation in numpy to speed up training.

5. (1) Clear structure of two classes

   (2) I implement a function to draw the decision tree, which I think is really cool.

   (3) Implement 5-fold validation

1.4 Performance Evaluation

kaggle username: Jack_xzh
Kaggle Score for Spam: 0.81099
Kaggle Score for Titanic: 0.80000

Accuracy for Spam Dataset

	Decision Tree	Random Forest
Training	0.8374	0.8225
Validation	0.8215	0.808

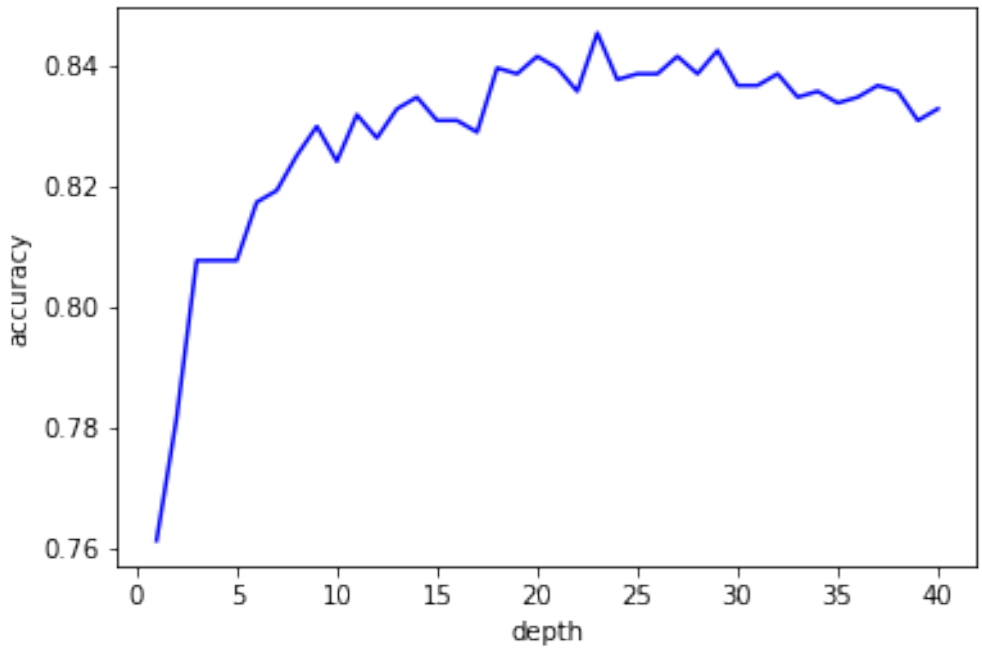
Accuracy for Titanic Dataset

	Decision Tree	Random Forest
Training	0.821	0.808
Validation	0.813	0.762

1.5 Writeup Requirements for the Spam Dataset

1. Do not include any new features
2. Example 1:
   (a) exclamation < 0.5
   (b) meter < 0.5
   (c) parenthesis < 0.5
   (d) volumes < 0.5
   (e) ampersand < 0.5
   (f) pain < 0.5
   (g) semicolon < 0.5
   (h) prescription < 0.5
   (i) square_bracket < 0.5
   (j) energy < 1.5
   (k) Therefore this email was Ham

   Example 2:
   (a) exclamation > 0.5
   (b) meter < 0.5
   (c) ampersand < 0.5
   (d) money < 0.5
   (e) dollar < 1.5
   (f) message < 0.5
   (g) prescription < 0.5
   (h) volumes < 0.5
   (i) semicolon < 0.5
   (j) pain < 0.5
   (k) Therefore this email was Spam
3. Here is the plot of validation accuracy

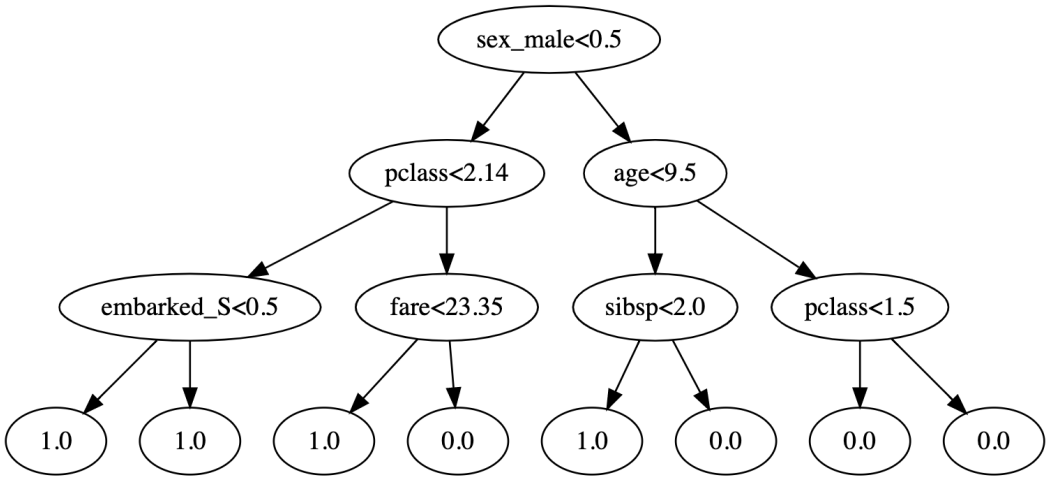


From the figure we can see that when depth equals 23, we can get the highest accuracy.

1.6 Writeup Requirements for the Titanic Dataset

```
def viz_tree(r,features):
    stack = []
    g = Digraph()# node_attr={'shape': 'record', 'height': '.1'})
    _id = 0
    current_node = r
    leftward = True
    current_root_num = 0

    while True:
        if current_node:
            stack.append((_id, current_node))
            if current_node.label!= None:
                g.node('node{0}'.format(_id), str(current_node.label))
            else:
                name = features[current_node.feature] + \
                       "<" + str(round(current_node.thresh,2))
                g.node('node{0}'.format(_id), name)
            if _id >= 1:
                g.edge('node{0}:f{1}'.format(current_root_num, \
                                             0 if leftward else 2),
                       'node{0}:f1'.format(_id))

            leftward = True
            current_node = current_node.left # left
            current_root_num = _id
            _id += 1

        if current_node is None and len(stack)!=0:
            count, popped_node = stack.pop()
            if popped_node.right:
                current_root_num = count
                current_node = popped_node.right # right
                leftward = False

        if current_node is None and len(stack)==0:
            break

    return g
```

Here is the decision tree I plotted with max_depth equals 3. Note: all the left nodes are smaller than the threshold and right are larger than threshold


sex_male<0.5
pclass<2.14
age<9.5
embarked_S<0.5
fare<23.35
sibsp<2.0
pclass<1.5
1.0
1.0
1.0
0.0
1.0
0.0
0.0
0.0

2 Appendix-Code

In [282]:
```
from collections import Counter
from tqdm import tnrange, tqdm_notebook
from sklearn import preprocessing
import pandas as pd
import numpy as np
from numpy import genfromtxt
import scipy.io
from scipy import stats
from sklearn.feature_extraction import DictVectorizer
import random
import csv
from graphviz import Digraph
```

In [169]:
```
# Usage results_to_csv(clf.predict(X_test))
def results_to_csv(y_test,dataname):
    y_test = y_test.astype(int)
    df = pd.DataFrame({'Category': y_test})
    df.index += 1  # Ensures that the index starts at 1.
    df.to_csv(dataname+'submission.csv', index_label='Id')
```

In [170]:
```
def viz_tree(r,features):
    stack = []
    g = Digraph()# node_attr={'shape': 'record', 'height': '.1'})
    _id = 0
    current_node = r
    leftward = True
    current_root_num = 0

    while True:
        if current_node:
            stack.append((_id, current_node))
            if current_node.label!= None:
                g.node('node{0}'.format(_id), str(current_node.label))
            else:
                name = features[current_node.feature] + \
                        "<" + str(round(current_node.thresh,2))
                g.node('node{0}'.format(_id), name)
            if _id >= 1:
                g.edge('node{0}:f{1}'.format(current_root_num, \
                                             0 if leftward else 2),
                       'node{0}:f1'.format(_id))

            leftward = True
            current_node = current_node.left  # left
            current_root_num = _id
            _id += 1
```

```
                if current_node is None and len(stack)!=0:
                    count, popped_node = stack.pop()
                    if popped_node.right:
                        current_root_num = count
                        current_node = popped_node.right  # right
                        leftward = False

                if current_node is None and len(stack)==0:
                    break

            return g
```

In [265]:
```
class Node:
    def __init__(self, left=None, right=None, label=None,\
                       feature=None,thresh=None):
        self.left = left
        self.right = right
        self.label = label
        self.feature = feature
        self.thresh = thresh

class DecisionTree:

    def __init__(self,max_depth = 10):
        self.max_depth = max_depth

    def entropy(self,y):
        _, counts = np.unique(y, return_counts=True)
        entropy_ = stats.entropy(counts, base=2)
        return entropy_

    def information_gain(self,y,left,right):

        entropy0 = self.entropy(y)
        Sl = len(left)
        Sr = len(right)
        entropy1 = (Sl * self.entropy(left) + \
                    Sr * self.entropy(right))/(Sl + Sr)

        return entropy0 - entropy1

    # split the X and y by idx and thresh
    def split(self,X, y, idx, thresh):
        left_filter = np.where(X[:,idx] < thresh)[0]
        right_filter = np.where(X[:,idx] >= thresh)[0]
        return X[left_filter], y[left_filter], \
               X[right_filter], y[right_filter]

    # return the thresh, info_gain
```

```
    def findSplitWithIndex(self,X,y,idx):
        mean = []
        col = sorted(np.unique(X[:,idx]))

        if len(col)==1:
            mean.append(0)

        for i in range(len(col)-1):
            mean.append( (col[i] + col[i+1])/2 )

        thresh = mean[0]
        info_ = 0
        for i in mean:
            xl,yl,xr,yr = self.split(X,y,idx,i)
            info_gain = self.information_gain(y,yl,yr)

            if info_gain > info_:
                info_ = info_gain
                thresh = i

        return thresh,info_

    # return the idx(figure), thresh
    def segmenter(self,X, y, m = None):
        info_ = 0
        thresh_ = 0
        idx_ = 0

        idxList = np.array(range(X.shape[1]))
        idxList = idxList[np.random.choice(X.shape[1], m,replace=False)]

        for idx in idxList:
            thresh,info_gain = self.findSplitWithIndex(X,y,idx)

            if info_gain > info_:
                info_ = info_gain
                thresh_ = thresh
                idx_ = idx

        return idx_,thresh_

    def fit_tree(self,X,y,depth=0,m=None):
        major_label = Counter(y).most_common(1)[0][0]
        if self.entropy(y)==0 or depth == self.max_depth:
            return Node(label=major_label)

        idx,thresh = self.segmenter(X,y,m=m)
        xl,yl,xr,yr = self.split(X,y,idx,thresh)
```

```
        if len(yl) > 0 and len(yr) >0:
            left = self.fit_tree(xl,yl,depth+1,m=m)
            right = self.fit_tree(xr,yr,depth+1,m=m)

            #label = "(" + idx + ")" + "<" + str(thresh)
            return Node(left,right,label=None,\
                        feature=idx,thresh=thresh)
        else:
            return Node(label=major_label)

    def fit(self, X, y,m=None):
        if m == None:
            m = X.shape[1]
        self.header = self.fit_tree(X,y,m=m)

    def predict(self, X):
        node = self.header
        pred = []

        for i in range(X.shape[0]):
            while node.label==None:
                if X[i][node.feature] < node.thresh:
                    node = node.left
                else:
                    node = node.right
            pred.append(node.label)
            node = self.header
        return pred

    def visualizeTree(self):
        return viz_tree(self.header,features)

    # state the splits (i.e., which feature and which value
    # of that feature to split on) your decision tree made
    # to classify it.
    def __repr__(self,x,features,class_names):
        node = self.header
        while node.label==None:
            if x[node.feature] < node.thresh:
                print(features[node.feature], "<", node.thresh)
                node = node.left
            else:
                print(features[node.feature], ">", node.thresh)
                node = node.right

        print("Therefore this email was",class_names[node.label])
```

```
class RandomForest(DecisionTree):

    def __init__(self,B=100,m=6,max_depth = 10):
        self.B = B
        self.m = m
        self.max_depth = max_depth

    def fit(self, X, y):
        self.forest = []
        for i in tqdm_notebook(range(self.B)):
            index = np.random.choice(X.shape[0], X.shape[0] ,\
                                     replace=True)
            X = X[index]
            y = y[index]
            self.forest.append(self.fit_tree(X,y,m=self.m))


    def predict(self, X):
        preds = []
        for i in range(X.shape[0]):
            pred = []
            for j in range(self.B):
                node = self.forest[j]
                while node.label==None:
                    if X[i][node.feature] < node.thresh:
                        node = node.left
                    else:
                        node = node.right
                pred.append(node.label)
            preds.append(Counter(pred).most_common(1)[0][0])
        return preds
```

```
In [252]: features = [
              "pain", "private", "bank", "money", "drug", "spam",
              "prescription", "creative", "height", "featured",
              "differ", "width", "other", "energy", "business",
              "message", "volumes", "revision", "path", "meter",
              "memo", "planning", "pleased", "record", "out",
              "semicolon", "dollar", "sharp", "exclamation",
              "parenthesis", "square_bracket", "ampersand"
          ]
          assert len(features) == 32

          # Load spam data
          path_train = 'datasets/spam-dataset/spam_data.mat'
          spamData = scipy.io.loadmat(path_train)
```

```
spamX = spamData['training_data']
spamY = np.squeeze(spamData['training_labels'])
spamTest = spamData['test_data']
class_names = ["Ham", "Spam"]

shuffle = np.arange(spamX.shape[0])
np.random.shuffle(shuffle)
spamX = spamX[shuffle]
spamY = spamY[shuffle]
```

In [253]:
```
classifier = DecisionTree(max_depth = 10)
accu = []
for i in range(5):
    index = np.array(range(int(i*5172/5),int((i+1)*5172/5)))

    testX = spamX[index]
    testY = spamY[index]

    trainX = np.delete(spamX,index,axis=0)
    trainY = np.delete(spamY,index,axis=0)

    classifier.fit(trainX,trainY)
    predictions = classifier.predict(testX)
    predictions = np.array(predictions)
    accu.append(sum(predictions == testY)/testY.size)
```

In [254]:
```
np.mean(accu)
```

Out[254]:
```
0.8197979797979797
```

In [255]:
```
classifier.fit(spamX,spamY)
predictions = classifier.predict(spamTest)
predictions = np.array(predictions)
```

In [256]:
```
results_to_csv(predictions,"spam")
```

In [266]:
```
classifier = DecisionTree(max_depth = 10)
classifier.fit(spamX,spamY)
classifier.__repr__(spamX[1],features,class_names)
```

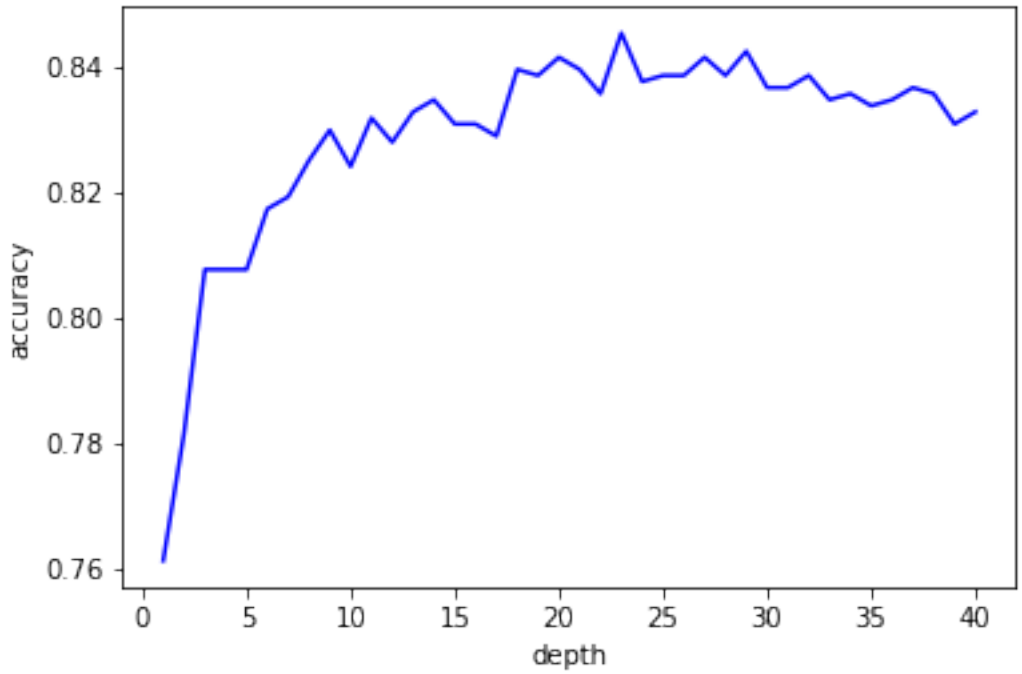
```
exclamation < 0.5
meter < 0.5
parenthesis < 0.5
volumes < 0.5
ampersand < 0.5
pain < 0.5
semicolon < 0.5
prescription < 0.5
square_bracket < 0.5
energy < 1.5
Therefore this email was Ham
```

In [267]:
```
classifier.__repr__(spamX[3],features,class_names)
```

```
exclamation > 0.5
meter < 0.5
ampersand < 0.5
money < 0.5
dollar < 1.5
message < 0.5
prescription < 0.5
volumes < 0.5
semicolon < 0.5
pain < 0.5
Therefore this email was Spam
```

In [268]:
```
# Pure depth
index = np.array(range(int(i*5172/5),int((i+1)*5172/5)))

testX = spamX[index]
testY = spamY[index]

trainX = np.delete(spamX,index,axis=0)
trainY = np.delete(spamY,index,axis=0)
accu = []

for i in range(40):
    classifier = DecisionTree(max_depth = i+1)

    classifier.fit(trainX,trainY)
    predictions = classifier.predict(testX)
    predictions = np.array(predictions)
    accu.append(sum(predictions == testY)/testY.size)
```

In [269]:
```
import matplotlib.pyplot as plt
%matplotlib inline
depth = list(range(1,41))
plt.plot(depth,accu,c="blue",)
plt.xlabel("depth")
plt.ylabel("accuracy")
plt.show()
```




```
In [241]: classifier = RandomForest(B=100,m=5,max_depth = 10)
          accu = []
          for i in range(5):
              index = np.array(range(int(i*5172/5),int((i+1)*5172/5)))

              testX = spamX[index]
              testY = spamY[index]

              trainX = np.delete(spamX,index,axis=0)
              trainY = np.delete(spamY,index,axis=0)

              classifier.fit(trainX,trainY)
              predictions = classifier.predict(testX)
              predictions = np.array(predictions)
              accu.append(sum(predictions == testY)/testY.size)
```

```
HBox(children=(IntProgress(value=0), HTML(value='')))
```

```
HBox(children=(IntProgress(value=0), HTML(value='')))
```

```
HBox(children=(IntProgress(value=0), HTML(value='')))
```

```
HBox(children=(IntProgress(value=0), HTML(value='')))
```

```
HBox(children=(IntProgress(value=0), HTML(value='')))
```

```
In [242]: np.mean(accu)
```

```
Out[242]: 0.8080088582401256
```

```
In [184]: # test
          classifier = RandomForest(B=50,m=6,max_depth = 20)
          classifier.fit(spamX, spamY)
```

```
HBox(children=(IntProgress(value=0, max=50), HTML(value='')))
```

```
In [243]: # training error
          classifier = RandomForest(B=50,m=6,max_depth = 20)
          # classifier = DecisionTree(max_depth = 10)
          classifier.fit(spamX, spamY)
          predictions = classifier.predict(spamX)
          predictions = np.array(predictions)
          sum(predictions == spamY)/5172
```

```
HBox(children=(IntProgress(value=0, max=50), HTML(value='')))
```

```
Out[243]: 0.8225058004640371
```

```
In [186]: predictions = classifier.predict(spamTest)
          predictions = np.array(predictions)
          results_to_csv(predictions,"spam")
```

In [270]:
```
# Load titanic data
train_data = pd.read_csv("datasets/titanic/titanic_training.csv")
test_data = pd.read_csv("datasets/titanic/titanic_testing_data.csv")
```

In [271]:
```
train_data.fillna(train_data.mean(),inplace=True)
test_data.fillna(test_data.mean(),inplace=True)
```

In [272]:
```
# one hot for training
train_data = pd.concat([train_data,
                        pd.get_dummies(train_data["sex"],
                        prefix="sex")],axis=1)
train_data.drop(["sex"], axis=1,inplace=True)

train_data = pd.concat([train_data,
                        pd.get_dummies(train_data["embarked"],
                        prefix="embarked")],axis=1)
train_data.drop(["embarked"], axis=1,inplace=True)

# one hot for testing
test_data = pd.concat([test_data,
                        pd.get_dummies(test_data["sex"],
                        prefix="sex")],axis=1)
test_data.drop(["sex"], axis=1,inplace=True)

test_data = pd.concat([test_data,
                        pd.get_dummies(test_data["embarked"],
                        prefix="embarked")],axis=1)
test_data.drop(["embarked"], axis=1,inplace=True)
```

In [273]:
```
train_y = train_data["survived"]
train_data.drop(["survived"], axis=1, inplace=True)
```

In [274]:
```
# drop ticket/cabin
train_data.drop(["ticket"], axis=1, inplace=True)
test_data.drop(["ticket"], axis=1, inplace=True)

train_data.drop(["cabin"], axis=1, inplace=True)
test_data.drop(["cabin"], axis=1, inplace=True)
```

In [275]:
```
features = list(train_data.columns)
```

In [276]:
```
train_data = train_data.values
train_y = train_y.values
test_data = test_data.values

shuffle = np.arange(train_data.shape[0])
np.random.shuffle(shuffle)
train_data = train_data[shuffle]
train_y = train_y[shuffle]
```

```
In [277]: classifier = DecisionTree(max_depth=5)
          accu = []
          for i in range(5):
              index = np.array(range(int(i*1000/5),int((i+1)*1000/5)))

              testX = train_data[index]
              testY = train_y[index]

              trainX = np.delete(train_data,index,axis=0)
              trainY = np.delete(train_y,index,axis=0)

              classifier.fit(trainX,trainY)
              predictions = classifier.predict(testX)
              predictions = np.array(predictions)
              accu.append(sum(predictions == testY)/testY.size)

          np.mean(accu)

Out[277]: 0.8140000000000001

In [278]: # pred
          classifier = DecisionTree(max_depth=4)
          classifier.fit(train_data, train_y)
          predictions = classifier.predict(train_data)
          predictions = np.array(predictions)
          sum(predictions == train_y)/1000

Out[278]: 0.821

In [279]: preds = classifier.predict(test_data)
          preds = np.array(preds)
          results_to_csv(preds,"tit")

In [ ]:

In [247]: classifier = RandomForest(B=100,m=3,max_depth = 5)
          accu = []
          for i in range(5):
              index = np.array(range(int(i*1000/5),int((i+1)*1000/5)))

              testX = train_data[index]
              testY = train_y[index]

              trainX = np.delete(train_data,index,axis=0)
              trainY = np.delete(train_y,index,axis=0)

              classifier.fit(trainX,trainY)
              predictions = classifier.predict(testX)
              predictions = np.array(predictions)
```

```
            accu.append(sum(predictions == testY)/testY.size)

        np.mean(accu)
```

```
HBox(children=(IntProgress(value=0), HTML(value='')))
```

```
HBox(children=(IntProgress(value=0), HTML(value='')))
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HBox(children=(IntProgress(value=0), HTML(value='')))
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HBox(children=(IntProgress(value=0), HTML(value='')))
```

```
HBox(children=(IntProgress(value=0), HTML(value='')))
```

```
Out[247]: 0.762
```

```
In [248]: # pred
          classifier.fit(train_data, train_y)
          predictions = classifier.predict(train_data)
          predictions = np.array(predictions)
          sum(predictions == train_y)/1000
```

```
HBox(children=(IntProgress(value=0), HTML(value='')))
```

```
Out[248]: 0.808
```

```
In [ ]: preds = classifier.predict(test_data)
        preds = np.array(preds)
        results_to_csv(preds,"tit")
```

```
In [ ]: classifier = DecisionTree(max_depth=3)
        classifier.fit(train_data, train_y)
        classifier.visualizeTree()
```