Lab Course Machine Learning

Exercise Sheet 9

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Syed Wasif Murtaza Jafri-311226

Exercise 1: Implement Decision Tree

In [11]:
```
import numpy as np
import math
from sklearn.preprocessing import PolynomialFeatures
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
from matplotlib import cm
from matplotlib.ticker import LinearLocator
from sympy import symbols, diff
import pandas as pd
import math
import warnings
import itertools
import matplotlib.colors as colors
from matplotlib.cm import ScalarMappable
from scipy.spatial.distance import pdist,cdist
warnings.filterwarnings('ignore')
from itertools import combinations
```

In [12]:
```
idf = pd.read_csv('iris.data',sep=',', header=None,names=['sepal_length', 'sepal_width','petal_length', 'petal_
idf
```

Out[12]:

	sepal_length	sepal_width	petal_length	petal_width	Y
0	5.1	3.5	1.4	0.2	Iris-setosa
1	4.9	3.0	1.4	0.2	Iris-setosa
2	4.7	3.2	1.3	0.2	Iris-setosa
3	4.6	3.1	1.5	0.2	Iris-setosa
4	5.0	3.6	1.4	0.2	Iris-setosa
...	...	...	...	...	...
145	6.7	3.0	5.2	2.3	Iris-virginica
146	6.3	2.5	5.0	1.9	Iris-virginica
147	6.5	3.0	5.2	2.0	Iris-virginica
148	6.2	3.4	5.4	2.3	Iris-virginica
149	5.9	3.0	5.1	1.8	Iris-virginica

150 rows × 5 columns

In [13]:
```
def splitDataframes(d):
    train, valid, test = 0.7, 0.15, 0.15



    data_train  = pd.DataFrame(columns=['sepal_length', 'sepal_width','petal_length', 'petal_width','Y'])
    data_valid  = pd.DataFrame(columns=['sepal_length', 'sepal_width','petal_length', 'petal_width','Y'])
    data_test   = pd.DataFrame(columns=['sepal_length', 'sepal_width','petal_length', 'petal_width','Y'])
#         np.unique(a, axis=0)
    classes = (d['Y'].unique())

    for c in classes:

        rowsWithc = d[d.Y == c]
        if(len(data_train)>0):
            data_train = data_train.append(rowsWithc[0:math.floor(len(rowsWithc)*0.7)])
        else:
            data_train = rowsWithc[0:math.floor(len(rowsWithc)*0.7)]
        if (len(data_valid)>0):
            data_valid = data_valid.append( rowsWithc[math.floor(len(rowsWithc)*0.7):math.floor(len(rowsWithc)*
        else:
            data_valid = rowsWithc[math.floor(len(rowsWithc)*0.7):math.floor(len(rowsWithc)*0.85)]
        if (len(data_test)>0):
            data_test = data_test.append( rowsWithc[math.floor(len(rowsWithc)*0.85):])
        else:
            data_test = rowsWithc[math.floor(len(rowsWithc)*0.85):]


    return data_train,data_valid,data_test
```

In [14]:
```
train ,val ,test = splitDataframes(idf)
```

In [15]:
```
train['Y'].value_counts()
```

Out[15]:
```
Iris-virginica     35
Iris-versicolor    35
Iris-setosa        35
Name: Y, dtype: int64
```

In [16]:
```
val['Y'].value_counts()
```

Out[16]:
```
Iris-virginica     7
Iris-versicolor    7
Iris-setosa        7
Name: Y, dtype: int64
```

In [17]:
```
test['Y'].value_counts()
```

Out[17]:
```
Iris-virginica     8
Iris-versicolor    8
Iris-setosa        8
Name: Y, dtype: int64
```

In [746…
```
class Node:
    def __init__ (self,data: pd.DataFrame,max_depth=None,depth=None,node_type=None,question=None,min_split_data
        self.data = data
        self.min_split_data = min_split_data
        self.X = data.loc[:, data.columns != 'Y']
        self.Y = data['Y']
        self.max_depth = max_depth
        self.depth = depth if depth else 0
        self.features = list(self.X.columns)
        self.question = question
        self.node_type = node_type if node_type else 'root'
        self.left = None
        self.right = None
        self.classes = (self.Y.unique())
        self.classCount = self.Y.value_counts()
        self.classProbablities = self.classCount/len(self.data)
        self.prediction = None

    def gini_impurity():
        pass

    def bestSplit(self):
        minMCR = 1
        for f in self.features:
            typeOfFeature = self.data[f].dtype
            columData = self.data[f]
            if(typeOfFeature == 'float64'):
                columData = columData.sort_values()
                columData = columData.unique()
                averageList = [(a + b) / 2 for a, b in zip(columData[::2], columData[1::2])] # taking average o
                for item in averageList:
                    # left
                    split1 = self.data[self.data[f] < item] # for each average value divinding dataframe into t
                    outputCounts1 = split1['Y'].value_counts() #counting outputs for each split
                    if (len(outputCounts1)>1): # no missclassification if only one element
                        misClassCounts1 = outputCounts1.loc[~outputCounts1.index.isin([outputCounts1.idxmax()])
                    else:
                        misClassCounts1 = 0

                    # right
                    split2  =self.data[self.data[f] >= item]
                    outputCounts2 = split2['Y'].value_counts()
                    if (len(outputCounts2)>1):
                        misClassCounts2 = outputCounts2.loc[~outputCounts2.index.isin([outputCounts2.idxmax()])
                    else:
                        misClassCounts2 = 0

                    totalMissclass = misClassCounts1 + misClassCounts2 # adding missclassification for left and
                    MCR = totalMissclass/len(self.data) # calculating mcr by dividing with total number of data

                    if(MCR<minMCR): # best split with minimum mcr
                        minMCR = MCR
                        bestFeature = f
                        bestValue = item

        print(minMCR)
        print('rule =',bestFeature ,'<', bestValue)

        return bestFeature,bestValue,typeOfFeature
    def entropy(self,data:pd.DataFrame):
        Y = data['Y']
        classCount = Y.value_counts()
        classProbablities = classCount/len(data)
        CE = 0
        for i in classProbablities:
            CE = CE - i*math.log(i,2)
        return CE



    def applySplit(self,bestFeature,bestValue,typeOfFeature):
        leftSplit = self.data.query(bestFeature +'<'+ str(bestValue))
        rightSplit = self.data.query(bestFeature +'>='+ str(bestValue))
        return leftSplit,rightSplit

    def learnDecisionTree(self):

        if (len(self.classes) > 1 and (self.depth < self.max_depth) and   len(self.data) > self.min_split_data)
            bestFeature,bestValue,typeOfFeature = self.bestSplit()

            self.question = bestFeature+'<'+str(bestValue)
            leftSplit,rightSplit = self.applySplit(bestFeature,bestValue,typeOfFeature)

            left = Node(leftSplit,5,self.depth+1,'left_node',None,5)
            self.left =  left
            self.left.learnDecisionTree()

            right = Node(rightSplit,5,self.depth+1,'right_node',None,5)
            self.right = right
            self.right.learnDecisionTree()
        else:
            self.prediction = self.classCount.idxmax()


    def breadth_first_search(self, root=None,width = 4 ):
        levelDict = {}
        root = self.root if root is None else root
        to_visit = [root]
        hisList = [root]
        while to_visit:
            current = to_visit.pop(0)
            const = int(current.depth * width ** 1.5)
            if(levelDict.get(current.depth)!=None ):
                    nodes = levelDict.get(current.depth)
                    nodes.append(current)
                    levelDict.update({current.depth:nodes})
            else:
                    nodes = []
                    nodes.append(current)
                    levelDict.update({current.depth:nodes})
            if(current.prediction == None):
                print(f"{'-' * const}  {current.depth} | Split rule: {current.question}")

                if current.left:
                    to_visit.append(current.left)
                    hisList.append(current.left)
                if current.right:
                    to_visit.append(current.right)
                    hisList.append(current.right)
            else:
                print(f"{'-' * const}  {current.depth} | Prediction: {current.prediction}")

        return hisList,levelDict

    def histogram(self, root=None,width = 4 ):

        root = self.root if root is None else root
        to_visit = [root]

        while to_visit:
            current = to_visit.pop(0)
            const = int(current.depth * width ** 1.5)
            if(current.prediction == None):
                axes = current.classProbablities.plot.bar(title= current.question + ' level:'+ str(current.dept
                if current.left:
                    to_visit.append(current.left)
                if current.right:
                    to_visit.append(current.right)
            else:
                axes = current.classProbablities.plot.bar(title= current.prediction + ' level:'+ str(current.de
    def predict_Class(self, X_test:pd.DataFrame) :

        curNode = self
        best_feature,best_value = curNode.question.split('<')
        if (X_test[best_feature] < float(best_value)):
            if self.left is not None:
                curNode = curNode.left
        else:
            if self.right is not None:
                    curNode = curNode.right
        while curNode.depth < curNode.max_depth and (curNode.question!=None):
            best_feature,best_value = curNode.question.split('<')
            if len(curNode.Y) < curNode.min_split_data :
                break
            if (X_test[best_feature] < float(best_value)):

                if self.left is not None:
                    curNode = curNode.left
            else:
                if self.right is not None:
                    curNode = curNode.right

        return curNode.prediction

    def predict(self, d_test:pd.DataFrame ):
        X_test = d_test.loc[:, d_test.columns != 'Y']
        Y_test = d_test['Y']
        Y_hat = []
        for index, row in X_test.iterrows():
            Y_hat.append(self.predict_Class(row))
        return (Y_hat)
```

In [747…
```
root = Node(train,5,1,'root',None,5)
```

In [748…
```
root.learnDecisionTree()
```

```
0.3333333333333333
rule = petal_length < 2.5999999999999996
0.08571428571428572
rule = petal_length < 4.85
0.030303030303030304
rule = petal_width < 1.65
0.10810810810810811
rule = sepal_length < 5.65
0.1111111111111111
rule = sepal_length < 5.75
```

In [749…
```
Y_hat = root.predict(val)
val['Y_hat'] = Y_hat
```

In [750…
```
histList,levelDict = root.breadth_first_search(root)
```

```
--------  1 | Split rule: petal_length<2.5999999999999996
----------------  2 | Prediction: Iris-setosa
----------------  2 | Split rule: petal_length<4.85
------------------------  3 | Split rule: petal_width<1.65
------------------------  3 | Split rule: sepal_length<5.65
--------------------------------  4 | Prediction: Iris-versicolor
--------------------------------  4 | Prediction: Iris-virginica
--------------------------------  4 | Prediction: Iris-virginica
--------------------------------  4 | Split rule: sepal_length<5.75
----------------------------------------  5 | Prediction: Iris-virginica
----------------------------------------  5 | Prediction: Iris-virginica
```

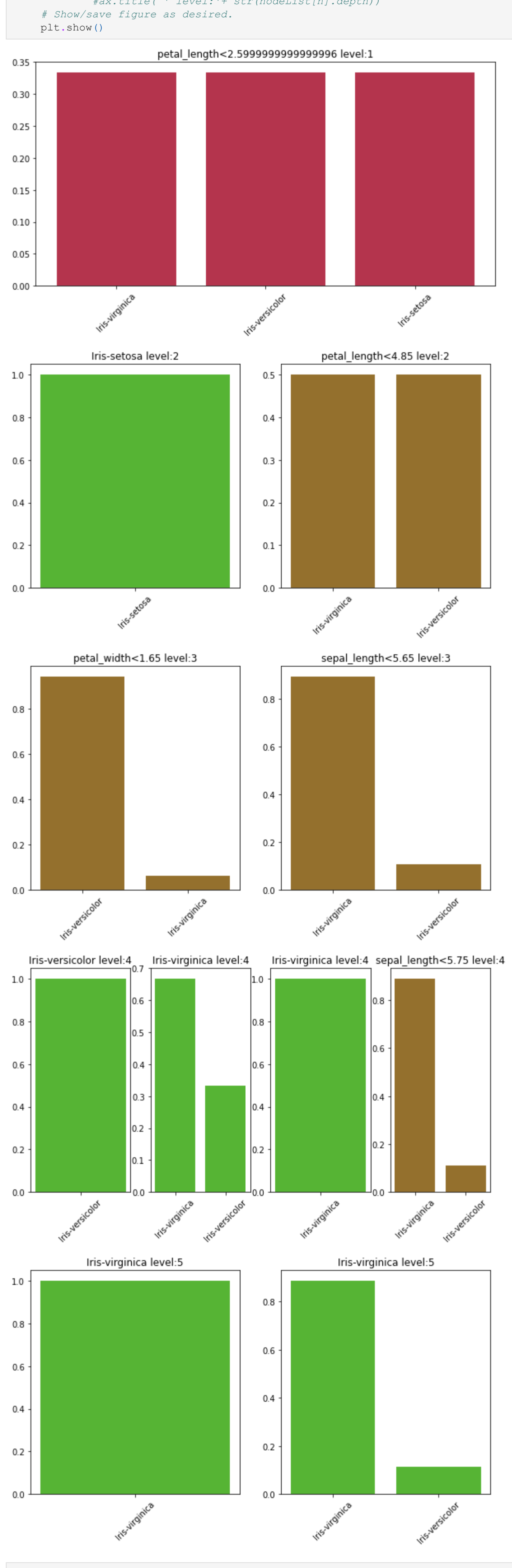
In [751…
```
for current in histList:
    const = int(current.depth * 4 ** 1.5)
    if(current.prediction == None):
        print(f"{'-' * const}  {current.depth} | Split rule: {current.question}")
    else:
        print(f"{'-' * const}  {current.depth} | Prediction: {current.prediction}")
```

```
--------  1 | Split rule: petal_length<2.5999999999999996
----------------  2 | Prediction: Iris-setosa
----------------  2 | Split rule: petal_length<4.85
------------------------  3 | Split rule: petal_width<1.65
------------------------  3 | Split rule: sepal_length<5.65
--------------------------------  4 | Prediction: Iris-versicolor
--------------------------------  4 | Prediction: Iris-virginica
--------------------------------  4 | Prediction: Iris-virginica
--------------------------------  4 | Split rule: sepal_length<5.75
----------------------------------------  5 | Prediction: Iris-virginica
----------------------------------------  5 | Prediction: Iris-virginica
```

In [752…
```
for i in levelDict:
    nodeList = levelDict.get(i)
    plt.figure(figsize=(10, 5))

    for n in range(len(nodeList)):
        if nodeList[n].node_type== 'root':
            ax = plt.subplot(1,len(nodeList),n+1)
            ax.bar(nodeList[n].classProbablities.index,nodeList[n].classProbablities,color='#B4344D')
            ax.title.set_text(nodeList[n].question + ' level:'+ str(nodeList[n].depth))
            ax.set_xticklabels(labels = nodeList[n].classProbablities.index,rotation=45)
        else:
            ax = plt.subplot(1,len(nodeList),n+1)
            if(nodeList[n].prediction == None):
                ax.title.set_text(nodeList[n].question + ' level:'+ str(nodeList[n].depth))
                ax.bar(nodeList[n].classProbablities.index,nodeList[n].classProbablities,color='#94702D')
                ax.set_xticklabels(labels = nodeList[n].classProbablities.index,rotation=45)
            else:
                ax.title.set_text(nodeList[n].prediction + ' level:'+ str(nodeList[n].depth))
                ax.bar(nodeList[n].classProbablities.index,nodeList[n].classProbablities,color='#56B434')
                ax.set_xticklabels(labels = nodeList[n].classProbablities.index,rotation=45)

            #ax.title( ' level:'+ str(nodeList[n].depth))
    # Show/save figure as desired.
    plt.show()
```



In [753…
```
def crossEntropy(data:pd.DataFrame):
    Y = data['Y']
    classCount = Y.value_counts()
    classProbablities = classCount/len(data)

    print(classProbablities)
    CE = 0
    for i in classProbablities:
        print (i)
        CE = CE - i*math.log(i)
        print (CE)

    return CE
```

In [754…
```
CE = crossEntropy(train)
CE
```

```
Iris-virginica     0.333333
Iris-versicolor    0.333333
Iris-setosa        0.333333
Name: Y, dtype: float64
0.3333333333333333
0.3662040962227032
0.3333333333333333
0.7324081924454064
0.3333333333333333
1.0986122886681096
```

Out[754… 1.0986122886681096

In [755…
```
alist = []
lst = ["a" ,"b", "c",'d','e']
print(math.ceil(len(lst)/2)+1)
lengthOfStrings = list(range(1,math.ceil(len(lst)/2)+1))
for l in (lengthOfStrings):
    for i in combinations(lst, l):
        if list(i) not in alist:
            c = [a  for a in lst if a not in i]
            alist.append(c)
            print(list(i), '-----',c )
```

```
4
['a'] ----- ['b', 'c', 'd', 'e']
['b'] ----- ['a', 'c', 'd', 'e']
['c'] ----- ['a', 'b', 'd', 'e']
['d'] ----- ['a', 'b', 'c', 'e']
['e'] ----- ['a', 'b', 'c', 'd']
['a', 'b'] ----- ['c', 'd', 'e']
['a', 'c'] ----- ['b', 'd', 'e']
['a', 'd'] ----- ['b', 'c', 'e']
['a', 'e'] ----- ['b', 'c', 'd']
['b', 'c'] ----- ['a', 'd', 'e']
['b', 'd'] ----- ['a', 'c', 'e']
['b', 'e'] ----- ['a', 'c', 'd']
['c', 'd'] ----- ['a', 'b', 'e']
['c', 'e'] ----- ['a', 'b', 'd']
['d', 'e'] ----- ['a', 'b', 'c']
```

Part B: Experimenting with other Quality-criterion:

In [761…
```
class Node:
    def __init__ (self,data: pd.DataFrame,max_depth=None,depth=None,node_type=None,question=None,min_split_data
        self.data = data
        self.min_split_data = min_split_data
        self.X = data.loc[:, data.columns != 'Y']
        self.Y = data['Y']
        self.max_depth = max_depth
        self.depth = depth if depth else 0
        self.features = list(self.X.columns)
        self.question = question
        self.node_type = node_type if node_type else 'root'
        self.left = None
        self.right = None
        self.classes = (self.Y.unique())
        self.classCount = self.Y.value_counts()
        self.classProbablities = self.classCount/len(self.data)
        self.prediction = None
        self.infoGain = None

    def gini_impurity():
        pass

        return bestFeature,bestValue,typeOfFeature
    def entropy(self,data:pd.DataFrame):
        Y = data['Y']
        classCount = Y.value_counts()
        classProbablities = classCount/len(data)
        CE = 0
        for i in classProbablities:
            CE = CE - i*math.log(i,2)
        return CE

    def bestSplitInfoGrain(self):
        infoGainBest = 0
        CE_data = self.entropy(self.data)
        for f in self.features:
            typeOfFeature = self.data[f].dtype
            columData = self.data[f]
            if(typeOfFeature == 'float64'):
                columData = columData.sort_values()
                columData = columData.unique()
                averageList = [(a + b) / 2 for a, b in zip(columData[::2], columData[1::2])] # taking average o
                for item in averageList:
                    # left
                    split1 = self.data[self.data[f] < item] # for each average value divinding dataframe into t

                    # right
                    split2  =self.data[self.data[f] >= item]


                    infoGain = CE_data-((len(split1)/len(self.data))*(self.entropy(split1)))-((len(split2)/len(

                    if(infoGain>infoGainBest): # best split with minimum mcr
                        infoGainBest = infoGain
                        bestFeature = f
                        bestValue = item

        print(infoGainBest)
        print('rule =',bestFeature ,'<', bestValue)

        return bestFeature,bestValue,typeOfFeature,infoGainBest

    def applySplit(self,bestFeature,bestValue,typeOfFeature):
        leftSplit = self.data.query(bestFeature +'<'+ str(bestValue))
        rightSplit = self.data.query(bestFeature +'>='+ str(bestValue))
        return leftSplit,rightSplit

    def learnDecisionTree(self):

        if (len(self.classes) > 1 and (self.depth < self.max_depth) and   len(self.data) > self.min_split_data)
            bestFeature,bestValue,typeOfFeature,infoGainBest = self.bestSplitInfoGrain()

            self.question = bestFeature+'<'+str(bestValue)
            self.infoGain = infoGainBest
            leftSplit,rightSplit = self.applySplit(bestFeature,bestValue,typeOfFeature)

            left = Node(leftSplit,5,self.depth+1,'left_node',None,5)
            self.left =  left
            self.left.learnDecisionTree()

            right = Node(rightSplit,5,self.depth+1,'right_node',None,5)
            self.right = right
            self.right.learnDecisionTree()
        else:
            self.prediction = self.classCount.idxmax()


    def breadth_first_search(self, root=None,width = 4 ):
        levelDict = {}
        root = self.root if root is None else root
        to_visit = [root]
        hisList = [root]
        while to_visit:
            current = to_visit.pop(0)
            const = int(current.depth * width ** 1.5)
            if(levelDict.get(current.depth)!=None ):
                    nodes = levelDict.get(current.depth)
                    nodes.append(current)
                    levelDict.update({current.depth:nodes})
            else:
                    nodes = []
                    nodes.append(current)
                    levelDict.update({current.depth:nodes})
            if(current.prediction == None):
                print(f"{'-' * const}  {current.depth} | Split rule: {current.question}")

                if current.left:
                    to_visit.append(current.left)
                    hisList.append(current.left)
                if current.right:
                    to_visit.append(current.right)
                    hisList.append(current.right)
            else:
                print(f"{'-' * const}  {current.depth} | Prediction: {current.prediction}")

        return hisList,levelDict

    def histogram(self, root=None,width = 4 ):

        root = self.root if root is None else root
        to_visit = [root]

        while to_visit:
            current = to_visit.pop(0)
            const = int(current.depth * width ** 1.5)
            if(current.prediction == None):
                axes = current.classProbablities.plot.bar(title= current.question + ' level:'+ str(current.dept
                if current.left:
                    to_visit.append(current.left)
                if current.right:
                    to_visit.append(current.right)
            else:
                axes = current.classProbablities.plot.bar(title= current.prediction + ' level:'+ str(current.de
    def predict_Class(self, X_test:pd.DataFrame) :

        curNode = self
        best_feature,best_value = curNode.question.split('<')
        if (X_test[best_feature] < float(best_value)):
            if self.left is not None:
                curNode = curNode.left
        else:
            if self.right is not None:
                    curNode = curNode.right
        while curNode.depth < curNode.max_depth and (curNode.question!=None):
            best_feature,best_value = curNode.question.split('<')
            if len(curNode.Y) < curNode.min_split_data :
                break
            if (X_test[best_feature] < float(best_value)):

                if self.left is not None:
                    curNode = curNode.left
            else:
                if self.right is not None:
                    curNode = curNode.right

        return curNode.prediction

    def predict(self, d_test:pd.DataFrame ):
        X_test = d_test.loc[:, d_test.columns != 'Y']
        Y_test = d_test['Y']
        Y_hat = []
        for index, row in X_test.iterrows():
            Y_hat.append(self.predict_Class(row))
        return (Y_hat)
```

In [795…
```
root = Node(train,5,1,'root',None,5)
a =[]
a.append(root)
```

In [796…
```
root.learnDecisionTree()
```

```
0.9182958340544894
rule = petal_length < 2.5999999999999996
0.5832901584817427
rule = petal_length < 4.85
0.2463646307476473
rule = petal_width < 1.65
0.181307493691589
rule = petal_length < 5.199999999999999
0.46666279373280384
rule = petal_width < 1.75
```

In [764…
```
Y_hat = root.predict(val)
val['Y_hat'] = Y_hat
```

In [765…
```
histList,levelDict = root.breadth_first_search(root)
```

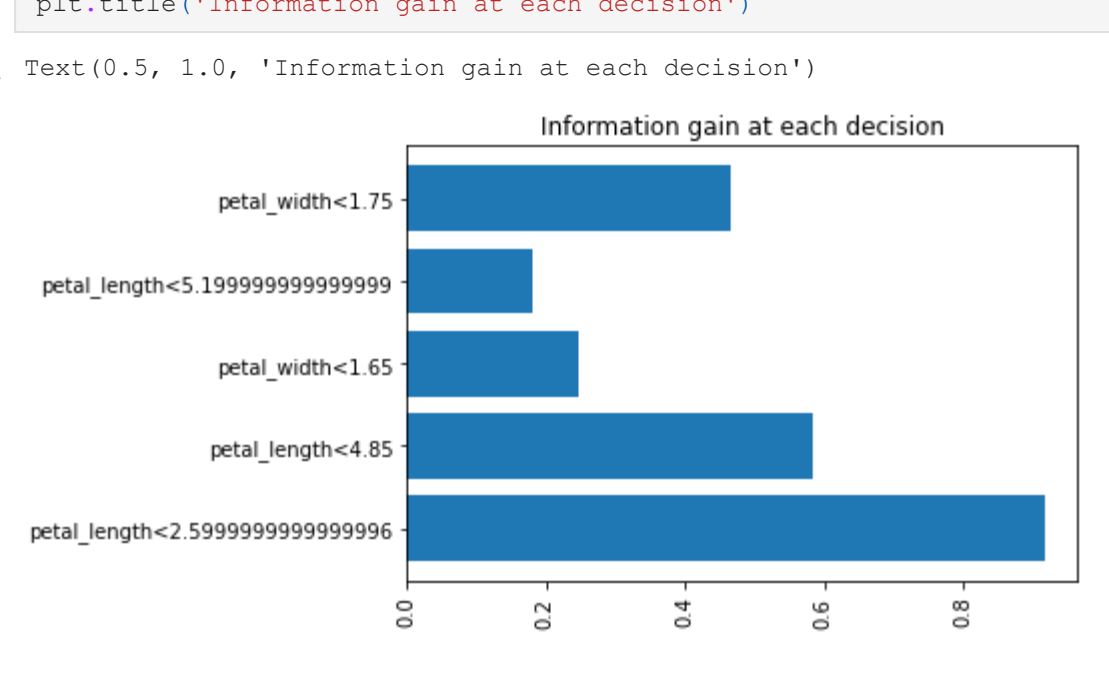
```
--------  1 | Split rule: petal_length<2.5999999999999996
----------------  2 | Prediction: Iris-setosa
----------------  2 | Split rule: petal_length<4.85
------------------------  3 | Split rule: petal_width<1.65
------------------------  3 | Split rule: petal_length<5.199999999999999
--------------------------------  4 | Prediction: Iris-versicolor
--------------------------------  4 | Prediction: Iris-virginica
--------------------------------  4 | Split rule: petal_width<1.75
--------------------------------  4 | Prediction: Iris-virginica
----------------------------------------  5 | Prediction: Iris-versicolor
----------------------------------------  5 | Prediction: Iris-virginica
```

In [766…
```
questionList = []
infoGainList = []
for current in histList:
    const = int(current.depth * 4 ** 1.5)
    if(current.prediction == None):
        print(f"{'-' * const}  {current.depth} | Split rule: {current.question} | infoGain: {current.infoGain}"
        questionList.append(current.question)
        infoGainList.append(current.infoGain)
    else:
        print(f"{'-' * const}  {current.depth} | Prediction: {current.prediction}")
```

```
--------  1 | Split rule: petal_length<2.5999999999999996 | infoGain: 0.9182958340544894
----------------  2 | Prediction: Iris-setosa
----------------  2 | Split rule: petal_length<4.85 | infoGain: 0.5832901584817427
------------------------  3 | Split rule: petal_width<1.65 | infoGain: 0.2463646307476473
------------------------  3 | Split rule: petal_length<5.199999999999999 | infoGain: 0.181307493691589
--------------------------------  4 | Prediction: Iris-versicolor
--------------------------------  4 | Prediction: Iris-virginica
--------------------------------  4 | Split rule: petal_width<1.75 | infoGain: 0.46666279373280384
--------------------------------  4 | Prediction: Iris-virginica
----------------------------------------  5 | Prediction: Iris-versicolor
----------------------------------------  5 | Prediction: Iris-virginica
```

In [775…
```
plt.barh(questionList,infoGainList)
plt.xticks(rotation=90)
plt.title('Information gain at each decision')
```

Out[775… Text(0.5, 1.0, 'Information gain at each decision')



Exercise 2: Gradient Boosted Decision Trees

In [125…
```
from sklearn.datasets import make_moons
```

In [125…
```
X, y = make_moons(random_state=0)
```

In [125…
```
df = pd.DataFrame(X, columns = ['x1','x2'])
df['Y'] = y
```

In [126…
```
df
```

Out[126…

	x1	x2	Y
0	-0.096023	0.995379	0
1	1.672301	-0.240278	1
2	0.991790	0.127877	0
3	0.050944	0.184892	1
4	1.032052	-0.499486	1
...	...	...	...
95	1.981559	0.308841	1
96	0.537462	-0.386599	1
97	0.376510	-0.281831	1
98	-0.991790	0.127877	0
99	-0.949056	0.315108	0

100 rows × 3 columns

In [126…
```
def splitDataframes(d):
    train, valid, test = 0.7, 0.15, 0.15



    data_train  = pd.DataFrame(columns=['x1', 'x2','Y'])
    data_valid  = pd.DataFrame(columns=['x1', 'x2','Y'])
    data_test   = pd.DataFrame(columns=['x1', 'x2','Y'])
#         np.unique(a, axis=0)
    classes = (d['Y'].unique())

    for c in classes:

        rowsWithc = d[d.Y == c]
        if(len(data_train)>0):
            data_train = data_train.append(rowsWithc[0:math.floor(len(rowsWithc)*0.7)])
        else:
            data_train = rowsWithc[0:math.floor(len(rowsWithc)*0.7)]
        if (len(data_valid)>0):
            data_valid = data_valid.append( rowsWithc[math.floor(len(rowsWithc)*0.7):math.floor(len(rowsWithc)*
        else:
            data_valid = rowsWithc[math.floor(len(rowsWithc)*0.7):math.floor(len(rowsWithc)*0.85)]
        if (len(data_test)>0):
            data_test = data_test.append( rowsWithc[math.floor(len(rowsWithc)*0.85):])
        else:
            data_test = rowsWithc[math.floor(len(rowsWithc)*0.85):]


    return data_train,data_valid,data_test
```

In [126…
```
train ,val ,test = splitDataframes(df)
```

In [126…
```
train= df[0:70]
train['Y'].value_counts()
```

Out[126…
```
0    36
1    34
Name: Y, dtype: int64
```

In [129…

```python
class Node:
    def __init__ (self,data: pd.DataFrame,max_depth=None,depth=None,node_type=None,question=None,min_split_data
        self.outputCol = outputCol
        self.data = data
        self.min_split_data = min_split_data
        self.X = data.iloc[:, 0:2]
        self.Y = data[self.outputCol]
        self.max_depth = max_depth
        self.depth = depth if depth else 0
        self.features = list(self.X.columns)
        self.question = question
        self.node_type = node_type if node_type else 'root'
        self.left = None
        self.right = None
        self.classes = (self.Y.unique())
        self.classCount = self.Y.value_counts()
        self.classProbablities = self.classCount/len(self.data)
        self.prediction = None
        self.infoGain = None
        self.previousProbablities = previousProbablities
        self.predictedProbablities = None


    def gini_impurity():
        pass

        return bestFeature,bestValue,typeOfFeature
    def entropy(self,data:pd.DataFrame):
        Y = data[self.outputCol]
        classCount = Y.value_counts()
        classProbablities = classCount/len(data)
        CE = 0
        for i in classProbablities:
            CE = CE - i*math.log(i,2)
        return CE

    def bestSplitInfoGrain(self):
        infoGainBest = 0
        CE_data = self.entropy(self.data)
        for f in self.features:
            typeOfFeature = self.data[f].dtype
            columData = self.data[f]
            if(typeOfFeature == 'float64'):
                columData = columData.sort_values()
                columData = columData.unique()
                averageList = [(a + b) / 2 for a, b in zip(columData[::2], columData[1::2])] # taking average o
                for item in averageList:
                    # left
                    split1 = self.data[self.data[f] < item] # for each average value dividing dataframe into t

                    # right
                    split2  =self.data[self.data[f] >= item]


                    infoGain = CE_data-((len(split1)/len(self.data))*(self.entropy(split1)))-((len(split2)/len(

                    if(infoGain>infoGainBest): # best split with minimum mcr
                        infoGainBest = infoGain
                        bestFeature = f
                        bestValue = item

        print(infoGainBest)
        print('rule =',bestFeature ,'<', bestValue)

        return bestFeature,bestValue,typeOfFeature,infoGainBest

    def applySplit(self,bestFeature,bestValue,typeOfFeature):
        leftSplit = self.data.query(bestFeature +'<'+ str(bestValue))
        rightSplit = self.data.query(bestFeature +'>='+ str(bestValue))
        return leftSplit,rightSplit

    def learnDecisionTree(self,previousProbablities=None):
        if(self.node_type== 'root'):
            self.data['previousProbablities'] = previousProbablities
        if(self.node_type == 'firstTree'):
            self.prediction = self.classCount.idxmax()
            predictedProbablities = []
            for i in self.Y:
                predictedProbablities.append(self.classProbablities[i])
            self.predictedProbablities = predictedProbablities

        elif (len(self.classes) > 1 and (self.depth < self.max_depth) and   len(self.data) > self.min_split_dat
            bestFeature,bestValue,typeOfFeature,infoGainBest = self.bestSplitInfoGrain()

            self.question = bestFeature+'<'+str(bestValue)
            self.infoGain = infoGainBest
            leftSplit,rightSplit = self.applySplit(bestFeature,bestValue,typeOfFeature)

            left = Node(leftSplit,self.max_depth,self.depth+1,'left_node',None,5,self.outputCol,self.previousPr
            self.left =  left
            self.left.learnDecisionTree()

            right = Node(rightSplit,self.max_depth,self.depth+1,'right_node',None,5,self.outputCol,self.previou
            self.right = right
            self.right.learnDecisionTree()
        else:
            numSum = 0
            dumSum = 0
            for index, row in self.data.iterrows():
                numSum = numSum + row['residual']
                dumSum = dumSum + (row['previousProbablities'])

            self.prediction = numSum/dumSum


    def breadth_first_search(self, root=None,width = 4 ):
        levelDict = {}
        root = self.root if root is None else root
        to_visit = [root]
        hisList = [root]
        while to_visit:
            current = to_visit.pop(0)
            const = int(current.depth * width ** 1.5)
            if(levelDict.get(current.depth)!=None ):
                    nodes = levelDict.get(current.depth)
                    nodes.append(current)
                    levelDict.update({current.depth:nodes})
            else:
                    nodes = []
                    nodes.append(current)
                    levelDict.update({current.depth:nodes})
            if(current.prediction == None):
                print(f"{'-' * const}  {current.depth} | Split rule: {current.question}")

                if current.left:
                    to_visit.append(current.left)
                    hisList.append(current.left)
                if current.right:
                    to_visit.append(current.right)
                    hisList.append(current.right)
            else:
                print(f"{'-' * const}  {current.depth} | Prediction: {current.prediction}")

        return hisList,levelDict

    def histogram(self, root=None,width = 4 ):

        root = self.root if root is None else root
        to_visit = [root]

        while to_visit:
            current = to_visit.pop(0)
            const = int(current.depth * width ** 1.5)
            if(current.prediction == None):
                axes = current.classProbablities.plot.bar(title= current.question + ' level:'+ str(current.dept
                if current.left:
                    to_visit.append(current.left)
                if current.right:
                    to_visit.append(current.right)
            else:
                axes = current.classProbablities.plot.bar(title= current.prediction + ' level:'+ str(current.de
    def predict_Class(self, X_test:pd.DataFrame)  :
        curNode = self
        if(self.node_type == 'firstTree'):
            return curNode.prediction

        best_feature,best_value = curNode.question.split('<')
        if (X_test[best_feature] < float(best_value)):
            if self.left is not None:
                curNode = curNode.left
        else:
            if self.right is not None:
                    curNode = curNode.right
        while curNode.depth < curNode.max_depth and (curNode.question!=None):
            best_feature,best_value = curNode.question.split('<')
            if len(curNode.Y) < curNode.min_split_data :
                break
            if (X_test[best_feature] < float(best_value)):

                if self.left is not None:
                    curNode = curNode.left
            else:
                if self.right is not None:
                    curNode = curNode.right

        return curNode.prediction

    def predict(self, d_test:pd.DataFrame ,learningRate):
        if(self.node_type == 'firstTree'):
            X_test = d_test.iloc[:, 0:2]
            Y_test = d_test['Y']
            Y_hat = []
            for index, row in X_test.iterrows():
                Y_hat.append(self.predict_Class(row))
            return (Y_hat)
        else:
            X_test = d_test.iloc[:, 0:2]
            Y_test = d_test[self.outputCol]
            predictedProbablities = []
            for index, row in d_test.iterrows():

                logOdd = row['previousProbablities'] + (learningRate *self.predict_Class(row))
                predictionProb = math.exp(logOdd)/(1+math.exp(logOdd))
                predictedProbablities.append(predictionProb)

            self.predictedProbablities = predictedProbablities
            print(np.array(predictedProbablities).sum())
            return (predictedProbablities)
```

In [129…

```python
listOfTrees =  []
predictedProbablities=[]
firstTree = Node(train,2,1,'firstTree',None,5,'Y',predictedProbablities)
firstTree.learnDecisionTree(predictedProbablities)
```

In [129…

```python
firstTree.classCount
```

Out[129…

```
0    36
1    34
Name: Y, dtype: int64
```

In [129…

```python
len (firstTree.predictedProbablities)
```

Out[129…

```
70
```

In [129…

```python
listOfTrees.append(firstTree)
```

In [129…

```python
Y_hat = firstTree.predict(train,0.2)
firstTree.classProbablities
```

Out[129…

```
0    0.514286
1    0.485714
Name: Y, dtype: float64
```

In [129…

```python
residual = []
predictedProbablities = []
for i,j in zip(train['Y'],Y_hat):
    residual.append(i-firstTree.classProbablities[j])
    predictedProbablities.append(firstTree.classProbablities[j])
```

In [130…

```python
train['residual'] = residual
train['predictedProbablities'] = predictedProbablities
```

In [130…

```python
train
```

Out[130…

	x1	x2	Y	residual	predictedProbablities	previousProbablities
0	-0.096023	0.995379	0	-0.514286	0.514286	0.597095
1	1.672301	-0.240278	1	0.485714	0.514286	0.684788
2	0.991790	0.127877	0	-0.514286	0.514286	0.618081
3	0.050944	0.184892	1	0.485714	0.514286	0.669787
4	1.032052	-0.499486	1	0.485714	0.514286	0.684788
...	...	...	...	...	...	...
65	1.623490	-0.281831	1	0.485714	0.514286	0.684788
66	-0.462538	0.886599	0	-0.514286	0.514286	0.597095
67	1.572117	-0.320172	1	0.485714	0.514286	0.684788
68	0.623490	0.781831	0	-0.514286	0.514286	0.597095
69	1.801414	-0.098111	1	0.485714	0.514286	0.684788

70 rows × 6 columns

In [130…

```python
numberofTree = 5
learningRate = 0.2
for i in range(1,5):

    tree = Node(train,2,1,'root',None,5,'residual',listOfTrees[i-1].predictedProbablities)
    tree.learnDecisionTree(predictedProbablities)
    predictedProbablities = tree.predict(tree.data,learningRate)
    train['predictedProbablities'] = predictedProbablities
    residual = []
    for i,j in zip(train['Y'],predictedProbablities):
        residual.append(i-j)
    train['residual'] = residual
    listOfTrees.append(tree)
```

```
0.40783647581206334
rule = x2 < 0.25
43.585290585256146
0.9994110647387553
rule = x2 < 0.25
44.720021370368016
0.9994110647387553
rule = x2 < 0.25
44.924161200606065
0.9994110647387553
rule = x2 < 0.25
44.9630740392363
```

In [130…

```python
for l in listOfTrees:
    print('----------------Tree-----------------')
    histList,levelDict = l.breadth_first_search(l)
```

```
----------------Tree-----------------
--------  1 | Prediction: 0
----------------Tree-----------------
--------  1 | Split rule: x2<0.25
----------------  2 | Prediction: 0.6584967320261441
----------------  2 | Prediction: -0.7299382716049385
----------------Tree-----------------
--------  1 | Split rule: x2<0.25
----------------  2 | Prediction: 0.30000685858020293
----------------  2 | Prediction: -0.7650123722212955
----------------Tree-----------------
--------  1 | Split rule: x2<0.25
----------------  2 | Prediction: 0.2697318345917814
----------------  2 | Prediction: -0.7714865805036665
----------------Tree-----------------
--------  1 | Split rule: x2<0.25
----------------  2 | Prediction: 0.2657543595677741
----------------  2 | Prediction: -0.7728606934477926
```

In [124…

Out[124…

	x1	x2	Y	residual	predictedProbablities	previousProbablities
0	-0.096023	0.995379	0	-0.598273	0.598273	0.598274
1	1.672301	-0.240278	1	0.314969	0.685031	0.685031
2	0.991790	0.127877	0	-0.618496	0.618496	0.618498
3	0.050944	0.184892	1	0.329840	0.670160	0.670160
4	1.032052	-0.499486	1	0.314969	0.685031	0.685031
...	...	...	...	...	...	...
65	1.623490	-0.281831	1	0.314969	0.685031	0.685031
66	-0.462538	0.886599	0	-0.598273	0.598273	0.598274
67	1.572117	-0.320172	1	0.314969	0.685031	0.685031
68	0.623490	0.781831	0	-0.598273	0.598273	0.598274
69	1.801414	-0.098111	1	0.314969	0.685031	0.685031

70 rows × 6 columns

In [ ]: