Q1

November 2, 2023

```python
[28]: from sklearn.preprocessing import OrdinalEncoder, OneHotEncoder
      from sklearn.ensemble import RandomForestClassifier, GradientBoostingClassifier
      from sklearn.model_selection import GridSearchCV
      import pandas as pd
      import numpy as np
      import statistics as stat
      from sklearn.datasets import load_iris
      from sklearn import tree
      from sklearn.metrics import accuracy_score
      import matplotlib.pyplot as plt
      import random
```

```python
[2]: label_encoder = None
```

```python
[3]: def get_np_array(file_name, encoding="onehot"):
         global label_encoder
         data = pd.read_csv(file_name)

         need_label_encoding = ['team','opp','host','month', 'day_match']
      #      if(label_encoder is None):
         if encoding == "ordinal":
             label_encoder = OrdinalEncoder()
         else:
             label_encoder = OneHotEncoder(sparse_output = False)
         label_encoder.fit(data[need_label_encoding])
         data_1 = pd.DataFrame(label_encoder.transform(data[need_label_encoding]),
      ↪columns = label_encoder.get_feature_names_out())

         #merge the two dataframes
         dont_need_label_encoding =  ["year","toss","bat_first","format"
      ↪,"fow","score" ,"rpo" ,"result"]
         data_2 = data[dont_need_label_encoding]
         final_data = pd.concat([data_1, data_2], axis=1)

         X = final_data.iloc[:,:-1]
         y = final_data.iloc[:,-1:]
         return X.to_numpy(), y.to_numpy()
```

```python
[4]: class DTNode:
         def __init__(self, depth, my_id=None, is_leaf=False, value=0, data=None,
     →columns=None, split_feature = None, split_feature_value = None, threshold =
     →None):
             #To uniquely identify a node
             self.my_id = my_id

             self.depth = depth

             #add children afterwards
             self.children = []

             #if leaf
             self.is_leaf = is_leaf

             #It stores the majority y
             self.value = value

             #Below attributes makes sense for decision nodes (non leaf nodes)
             self.split_feature = split_feature
             self.split_feature_value = split_feature_value #only makes sense for
     →categorical attributes. ex we want to move to children with weather="sunny"
             self.threshold = threshold #only makes sense for continouos attributes

             self.columns = columns
             self.data = data
```

```python
[5]: class DTTree:
         def __init__(self, X_train, y_train, types):
             #Tree root should be DTNode
             self.root = None

             self.X_train = X_train
             self.y_train = y_train
             self.types = types

             self.id_counter = 0

             self.columns = [i for i in range(X_train.shape[1])]
             self.data = np.array([i for i in range(len(X_train))])

         #returns a dictionary with unique values and corresponding split
         def get_data_split(self, data, idx):
             data_split = dict()
             # print(data)
             X_temp = self.X_train[data]
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            if self.types[idx] == 'cat':
                unique_vals = np.unique(X_temp[:,idx])
                for val in unique_vals:
                    indices = np.array([i for i, value in enumerate(X_temp[:,idx]
→== val) if value])
                    data_split[val] = data[indices]
                return data_split

            elif self.types[idx] == 'cont':
                median = stat.median(X_temp[:,idx])

                indices = np.array([i for i, value in enumerate(X_temp[:,idx] <=
→median) if value])
                if indices.shape[0] != 0:
                    data_split["less_than_equal"] = data[indices]

                indices = np.array([i for i, value in enumerate(X_temp[:,idx] >
→median) if value])
                if indices.shape[0] != 0:
                    data_split["more_than"] = data[indices]

                return data_split

    @staticmethod
    def compute_entropy(y, data):
        y_temp = y[data]
        unique_values, value_counts = np.unique(y_temp, return_counts=True)
        # print("unique values:",unique_values)
        # print("value_counts:",value_counts)
        entropy = 0
        for val in value_counts:
            p = val/value_counts.sum()
            entropy += (-1)*p*np.log2(p)
        return entropy, unique_values[0]

    @staticmethod
    def compute_entropy_attr(X, y, data, col, col_type=None):
        entropy = 0
        X_temp = X[data]
        y_temp = y[data]
        S = len(data)
        # print("total:",S)
        # print(col, col_type)
        if col_type == 'cat':
            unique_vals = np.unique(X_temp[:,col])
            for val in unique_vals:
                S_val = np.count_nonzero(X_temp[:,col]==val)
```

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                entropy_temp,_ = DTTree.compute_entropy(y_temp, X_temp[:
↪,col]==val)
                # print(val, S_val, entropy_temp)
                entropy += (S_val/S)*entropy_temp
        elif col_type == 'cont':
            median = stat.median(X_temp[:,col])
            S_val1 = np.count_nonzero(X_temp[:,col] <= median)
            S_val2 = np.count_nonzero(X_temp[:,col] > median)
            entropy_temp1,_ = DTTree.compute_entropy(y_temp, X_temp[:,col] <=␣
↪median)
            entropy_temp2,_ = DTTree.compute_entropy(y_temp, X_temp[:,col] >␣
↪median)
            # print(S_val1, entropy_temp1)
            # print(S_val2, entropy_temp2)
            entropy = ((S_val1/S)*entropy_temp1)+((S_val2/S)*entropy_temp2)
        return entropy

    def get_majority_y(self, data):
        y_temp = self.y_train[data]
        y_temp = y_temp.reshape(-1)
        return stat.mode(y_temp)

    def build_tree(self, this_node=None, data = None, columns = None):
        # print(data)
        entropy, y_pred = DTTree.compute_entropy(self.y_train, data)
        # print("entropy: ",entropy)
        #when entropy would be zero,only one type of y would be present, y_pred␣
↪makes sense else no
        if entropy == 0:
            this_node.is_leaf = True
            this_node.value = y_pred

            #Updating ID
            if this_node.my_id == None:
                this_node.my_id = self.id_counter
                self.id_counter += 1
            return this_node
        else:
            if(len(columns) == 0):
                this_node.is_leaf = True
                this_node.value = self.get_majority_y(data)

                #Updating ID
                if this_node.my_id == None:
                    this_node.my_id = self.id_counter
                    self.id_counter += 1
                return this_node
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```python
            #Splitting criteria
            entropy_cols = np.zeros(len(columns))
            IG_cols = np.zeros(len(columns))
            for i in range(len(columns)):
                entropy_cols[i] = DTTree.compute_entropy_attr(self.X_train,
→self.y_train, self.data, columns[i], self.types[columns[i]])
                IG_cols[i] = entropy - entropy_cols[i]
                # print(columns[i],IG_cols[i])
            #creating a node and returning
            idx = columns[np.argmax(IG_cols)]

            this_node.is_leaf = False
            this_node.split_feature = idx
            this_node.value = self.get_majority_y(data)
            this_node.columns = columns
            this_node.data = data

            data_split = DTTree.get_data_split(self, data, idx)

            if self.types[idx] == 'cat':
                # print(f"BUILD cat idx={idx}")
                for key,val in data_split.items():
                    new_columns = columns.copy()

                    new_columns.remove(idx)

                    child_node = DTNode(depth = this_node.depth + 1, my_id =
→self.id_counter, is_leaf=False, split_feature_value=key)
                    self.id_counter += 1
                    this_node.children.append(self.build_tree(child_node,
→data=val, columns=new_columns))
            elif self.types[idx] == 'cont':
                # print(f"BUILD cont idx={idx}")
                if len(data_split) > 1:
                    for key,val in data_split.items():
                        X_temp = self.X_train[data]
                        this_node.threshold = stat.median(X_temp[:,idx])
                        child_node = DTNode(depth = this_node.depth + 1, my_id
→= self.id_counter, is_leaf=False, split_feature_value=key)
                        self.id_counter += 1
                        this_node.children.append(self.build_tree(child_node,
→data=val, columns=columns))
                else:
                    new_columns = columns.copy()

                    new_columns.remove(idx)
```

```python
                for key,val in data_split.items():
                    X_temp = self.X_train[data]
                    this_node.threshold = stat.median(X_temp[:,idx])
                    child_node = DTNode(depth = this_node.depth + 1, my_id
                    = self.id_counter, is_leaf=False, split_feature_value=key)
                    self.id_counter += 1
                    this_node.children.append(self.build_tree(child_node,
                    data=val, columns=new_columns))

        return this_node
        # print("Attribute to split: ", columns[idx])

    @staticmethod
    def print_node(root):
        if root.is_leaf:
            print(f"I am leaf and my value is {root.value} and my depth is
            {root.depth}")
        else:
            # print(f"I am not a leaf and i have {len(root.children)} and my
            value is {root.value} and my depth is {root.depth}")
            for child in root.children:
                # print(f"parent info:: split feature: {root.split_feature},
                split feature value: {root.split_feature_value}, threshold: {root.
                threshold}")
                # print(f"split feature: {child.split_feature}, split feature
                value: {child.split_feature_value}, threshold: {child.threshold}")
                DTTree.print_node(child)

    def print_tree(self):
        DTTree.print_node(self.root)

    def predict(self, X_test, max_depth):
        y_test_pred = np.zeros((len(X_test),1))
        for index in range(len(X_test)):
            x = X_test[index]
            temp = self.root
            pred = None
            while(True):
                #Terminating condition
                if temp.is_leaf == True or temp.depth >= max_depth:
                    pred = temp.value
                    break

                split_feature = temp.split_feature
                type_split_feature = self.types[split_feature]
```

```python
                if type_split_feature == "cat":
                    z = x[split_feature]
                else:
                    if x[split_feature] <= temp.threshold:
                        z = "less_than_equal"
                    else:
                        z = "more_than"

                flag = 0

                for child in temp.children:
                    if child.split_feature_value == z:
                        temp = child
                        flag = 1

                #z not found in children, so return the prediction
                if flag == 0:
                    pred = temp.value
                    break

            y_test_pred[index][0] = pred

        return y_test_pred

    def execute(self):
        this_node = DTNode(depth=0, my_id=0, is_leaf=False)
        self.id_counter += 1
        self.root = self.build_tree(this_node = this_node, data = self.data,␣
↪columns = self.columns)
        print("Decision tree built successfully!")
```

Decision tree with both categorical attributes as well as continuous attributes (ordinal encoding)

```python
[6]: X_train,y_train = get_np_array('../Data/train.csv', encoding="ordinal")
     X_test, y_test = get_np_array("../Data/test.csv", encoding="ordinal")
     X_val, y_val = get_np_array("../Data/val.csv", encoding="ordinal")

     types = ['cat','cat','cat',"cat","cat","cont","cat","cat","cat" ,"cont","cont"␣
     ↪,"cont" ]
```

```python
[7]: dtree = DTTree(X_train,y_train, types)
     dtree.execute()
```

```
Decision tree built successfully!
```

```python
[8]: dtree.print_tree()
```

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I am leaf and my value is 0 and my depth is 3
I am leaf and my value is 0 and my depth is 9
I am leaf and my value is 1 and my depth is 9
I am leaf and my value is 1 and my depth is 5
I am leaf and my value is 0 and my depth is 9
I am leaf and my value is 1 and my depth is 9
I am leaf and my value is 0 and my depth is 5
I am leaf and my value is 0 and my depth is 8
I am leaf and my value is 1 and my depth is 8
I am leaf and my value is 0 and my depth is 5
I am leaf and my value is 1 and my depth is 9
I am leaf and my value is 0 and my depth is 9
I am leaf and my value is 0 and my depth is 8
I am leaf and my value is 1 and my depth is 8
I am leaf and my value is 1 and my depth is 3
I am leaf and my value is 0 and my depth is 3
I am leaf and my value is 1 and my depth is 5
I am leaf and my value is 0 and my depth is 5
I am leaf and my value is 1 and my depth is 4
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I am leaf and my value is 0 and my depth is 9
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I am leaf and my value is 1 and my depth is 8
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I am leaf and my value is 1 and my depth is 9
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```

```python
[9]: max_depth_list = [5,10,15,20,25]
     training_acc = []
     testing_acc = []

     for max_depth in max_depth_list:
         print("Max depth: ", max_depth)

         y_train_pred = dtree.predict(X_train, max_depth = max_depth)
         train_acc = accuracy_score(y_train, y_train_pred)
         print("training accuracy: ",train_acc)
         training_acc.append(train_acc)

         y_test_pred = dtree.predict(X_test, max_depth = max_depth)
         test_acc = accuracy_score(y_test, y_test_pred)
         print("testing accuracy: ",test_acc)
         testing_acc.append(test_acc)

         print("\n")
```

```
Max depth:  5
training accuracy:  0.8058004343937651
testing accuracy:  0.5842812823164426


Max depth:  10
training accuracy:  0.9753417656828925
testing accuracy:  0.5966907962771458


Max depth:  15
training accuracy:  0.9998722371278906
testing accuracy:  0.59358841778697


Max depth:  20
```

```
training accuracy:   0.9998722371278906
testing accuracy:   0.59358841778697
```

```
Max depth:   25
training accuracy:   0.9998722371278906
testing accuracy:   0.59358841778697
```

[10]:
```python
#Plot training and testing accuracies for different max_depth
plt.figure(figsize=(10,5))
plt.plot(max_depth_list, training_acc, marker='o', markersize=6, color='blue',
 ↪label='Training Accuracies')
plt.plot(max_depth_list, testing_acc, marker='o', markersize=6, color='red',
 ↪label='Testing Accuracies')

plt.title('Training and Testing accuracy vs max_depth')
plt.xlabel('max_depth')
plt.ylabel('Accuracy')
plt.xticks(max_depth_list)
plt.ylim(0,1.1)
plt.legend()
plt.show()
```
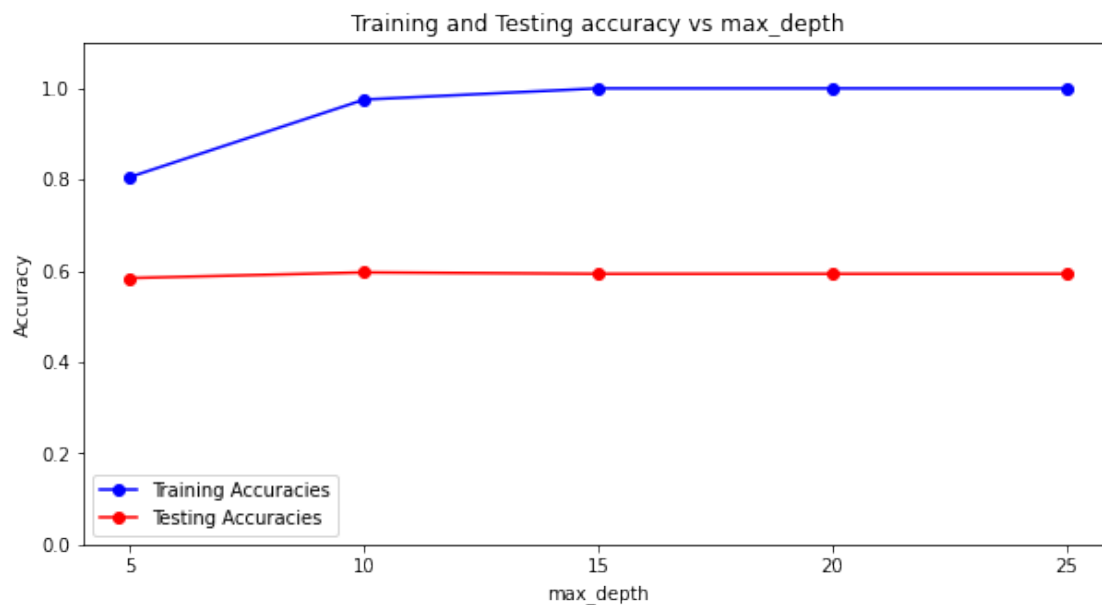

Only win prediction on test data

```
[11]: y_test_pred = np.ones((len(X_test),1))
      print("[ONLY WIN]testing accuracy: ",accuracy_score(y_test, y_test_pred))
```

[ONLY WIN]testing accuracy: 0.4963805584281282

Only loss prediction on test data

```
[12]: y_test_pred = np.zeros((len(X_test),1))
      print("[ONLY LOSS]testing accuracy: ",accuracy_score(y_test, y_test_pred))
```

[ONLY LOSS]testing accuracy: 0.5036194415718718

Decision tree with only categorical attributes (one-hot encoding)

```
[7]: X_train,y_train = get_np_array('../Data/train.csv', encoding="onehot")
     X_test, y_test = get_np_array("../Data/test.csv", encoding="onehot")
     X_val, y_val = get_np_array("../Data/val.csv", encoding="onehot")
```

```
[8]: types = ['cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat',
      →'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat',
      →'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat',
      →'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat',
      →'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat',
      →'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat',
      →'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cont', 'cat', 'cat',
      →'cat', 'cont', 'cont', 'cont']
```

```
[9]: # dtree_1h = DTTree(X_train,y_train, types)
     # dtree_1h.execute()
```

```
[45]: import pickle

      # file = open('dtree_1h.obj','wb')
      # pickle.dump(dtree_1h,file)
      # file.close()
```

```
[46]: rfile = open('dtree_1h.obj','rb')
      dtree_1h = pickle.load(rfile)
      rfile.close()
      print("Decision tree loaded!")
```

Decision tree loaded!

```
[12]: dtree_1h.print_tree()
```

I am leaf and my value is 0 and my depth is 63
I am leaf and my value is 1 and my depth is 63
I am leaf and my value is 1 and my depth is 50
I am leaf and my value is 0 and my depth is 64

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I am leaf and my value is 0 and my depth is 54
I am leaf and my value is 1 and my depth is 54
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```python
[13]: # for idx in range(dtree_1h.X_train.shape[1]):
      #     unique_vals = np.unique(dtree_1h.X_train[:,idx])
      #     print(idx, len(unique_vals))
```

```python
[14]: max_depth_list = [15,25,35,45,55,65,75]
      training_acc = []
      testing_acc = []

      for max_depth in max_depth_list:
          print("Max depth: ", max_depth)

          y_train_pred = dtree_1h.predict(X_train, max_depth = max_depth)
          train_acc = accuracy_score(y_train, y_train_pred)
          print("training accuracy: ",train_acc)
          training_acc.append(train_acc)

          y_test_pred = dtree_1h.predict(X_test, max_depth = max_depth)
          test_acc = accuracy_score(y_test, y_test_pred)
          print("testing accuracy: ",test_acc)
          testing_acc.append(test_acc)

          print("\n")
```

```
Max depth:  15
training accuracy:  0.5935863038201099
testing accuracy:  0.5594622543950362
```

```
Max depth:  25
training accuracy:  0.6211830841957328
testing accuracy:  0.5791106514994829


Max depth:  35
training accuracy:  0.6443081640475278
testing accuracy:  0.5811789038262668


Max depth:  45
training accuracy:  0.7093394659511946
testing accuracy:  0.5966907962771458


Max depth:  55
training accuracy:  0.8652101699246199
testing accuracy:  0.6018614270941055


Max depth:  65
training accuracy:  0.9630765299603935
testing accuracy:  0.5956566701137539


Max depth:  75
training accuracy:  1.0
testing accuracy:  0.6008273009307136
```

[15]:
```python
#Plot training and testing accuracies for different max_depth
plt.figure(figsize=(10,5))
plt.plot(max_depth_list, training_acc, marker='o', markersize=6, color='blue',
 →label='Training Accuracies')
plt.plot(max_depth_list, testing_acc, marker='o', markersize=6, color='red',
 →label='Testing Accuracies')

plt.title('Training and Testing accuracy vs max_depth')
plt.xlabel('max_depth')
plt.ylabel('Accuracy')
plt.xticks(max_depth_list)
plt.ylim(0,1.1)
plt.legend()
plt.show()
```

Training and Testing accuracy vs max_depth
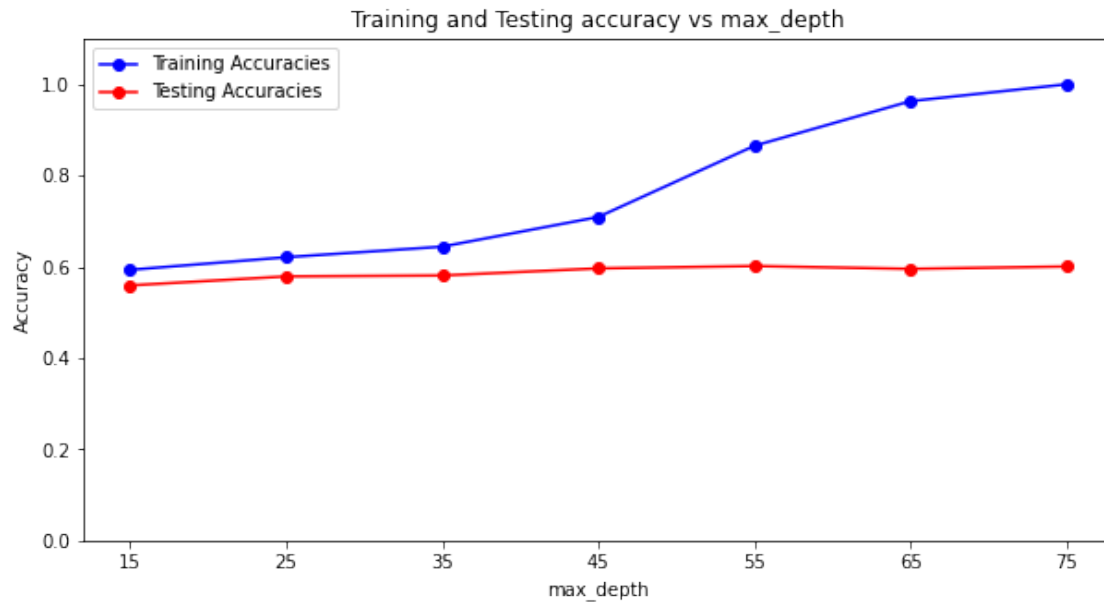
```
[47]: def count_nodes(root):
          if root.is_leaf == True:
              return 1
          count = 1
          for child in root.children:
              count += count_nodes(child)
          return count
```

```
[48]: # count_nodes(dtree.root)
```

```
[49]: count_nodes(dtree_1h.root)
```

```
[49]: 26753
```

Post pruning in decision tree

```
[120]: X_train,y_train = get_np_array('../Data/train.csv', encoding="onehot")
       X_test, y_test = get_np_array("../Data/test.csv", encoding="onehot")
       X_val, y_val = get_np_array("../Data/val.csv", encoding="onehot")
```

```python
types = ['cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat',
→'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat',
→'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat',
→'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat',
→'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat',
→'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat',
→'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cat', 'cont', 'cat', 'cat',
→'cat', 'cont', 'cont', 'cont']
```

[133]:
```python
#Dictionary to store the children info
children = dict()

#List of non leaf nodes
non_leaf_node_ids = []

#It stores the children dictionary and fills up the list of non_leaf_node_ids
→subject to max_depth
def store_children_info(root, max_depth):
    global children, non_leaf_node_ids
    if root.is_leaf == True or root.depth >= max_depth:
        a=1 #dummy statement
    else:
        non_leaf_node_ids.append(root.my_id)
        for child in root.children:
            children[root.my_id] = children[root.my_id] + [child.my_id]
            store_children_info(child, max_depth)

#It returns the list of all children, grand children, .. of idx with help of
→children dict
def return_all_childrens(children, idx):
    mega_lst = children[idx]
    for child in children[idx]:
        mega_lst = mega_lst + return_all_childrens(children, child)
    return mega_lst
```

[134]:
```python
def predict_new(root, types, X_test, y_test, non_leaf_considered_leaf,
→max_depth):
    y_test_pred = np.zeros((len(X_test),1))
    for index in range(len(X_test)):
        x = X_test[index]
        temp = root
        pred = None
        while(True):
            #Terminating condition
            if temp.depth >= max_depth or (temp.is_leaf == True) or (temp.my_id
→in non_leaf_considered_leaf):
                pred = temp.value
```

```python
                break

            split_feature = temp.split_feature
            type_split_feature = types[split_feature]

            if type_split_feature == "cat":
                z = x[split_feature]
            else:
                if x[split_feature] <= temp.threshold:
                    z = "less_than_equal"
                else:
                    z = "more_than"

            flag = 0

            for child in temp.children:
                if child.split_feature_value == z:
                    temp = child
                    flag = 1

            #z not found in children, so return the prediction
            if flag == 0:
                pred = temp.value
                break

        y_test_pred[index][0] = pred

    acc = accuracy_score(y_test, y_test_pred)
    return acc

def post_pruning(root, max_depth):
    no_non_leaf_nodes = []
    train_acc = []
    test_acc = []
    val_acc = []

    prob_pruning_when_no_improvement = 0.25

    global children, non_leaf_node_ids
    #Reinitializing the children dict
    children = dict()
    for i in range(count_nodes(dtree_1h.root)):
        children[i]= []

    #Reinitializing non leaf node ids
    non_leaf_node_ids = []
```

```python
    store_children_info(dtree_1h.root, max_depth)

    v_acc = predict_new(root, types, X_val, y_val, non_leaf_considered_leaf =
↪[], max_depth= max_depth)
    tr_acc = predict_new(root, types, X_train, y_train,
↪non_leaf_considered_leaf = [], max_depth= max_depth)
    te_acc = predict_new(root, types, X_test, y_test, non_leaf_considered_leaf
↪= [], max_depth= max_depth)

    no_non_leaf_nodes.append(len(non_leaf_node_ids))
    train_acc.append(tr_acc)
    test_acc.append(te_acc)
    val_acc.append(v_acc)


    print(f"Initial validation accuracy: {v_acc}")

    random.shuffle(non_leaf_node_ids)

    #Below code would store the non leaf which would be considered as leaf
↪based on validation accuracy
    non_leaf_considered_leaf = []

    while(len(non_leaf_node_ids) > 0):
        scores = np.zeros(len(non_leaf_node_ids))
        for i in range(len(non_leaf_node_ids)):
            scores[i] = predict_new(root, types, X_val, y_val,
↪non_leaf_considered_leaf = non_leaf_considered_leaf +
↪[non_leaf_node_ids[i]], max_depth= max_depth) - v_acc
        k = np.argmax(scores)
        curr_node = non_leaf_node_ids[k]
        if scores[k] < 0:
            break
        elif scores[k] == 0 and np.random.sample() <
↪prob_pruning_when_no_improvement:
            break

        v_acc = v_acc + scores[k]
        tr_acc = predict_new(root, types, X_train, y_train,
↪non_leaf_considered_leaf = non_leaf_considered_leaf + [curr_node],
↪max_depth= max_depth)
        te_acc = predict_new(root, types, X_test, y_test,
↪non_leaf_considered_leaf = non_leaf_considered_leaf + [curr_node],
↪max_depth= max_depth)

        no_non_leaf_nodes.append(len(non_leaf_node_ids))
```

```python
        train_acc.append(tr_acc)
        test_acc.append(te_acc)
        val_acc.append(v_acc)

        non_leaf_node_ids.remove(curr_node)
        #update non_leaf_node_ids (in case when curr_node would be considered␣
→leaf)
        children_of_curr_node = return_all_childrens(children, curr_node)
        non_leaf_node_ids = [item for item in non_leaf_node_ids if item not in␣
→children_of_curr_node]
        non_leaf_considered_leaf = non_leaf_considered_leaf + [curr_node]
        print(f"Validation accuracy is {v_acc}. node with id:{curr_node} is now␣
→a leaf node. unvisited_non_leaf_nodes:{len(non_leaf_node_ids)}")

    #Training accuracy
    print("Final Training accuracy: ",predict_new(root, types, X_train,␣
→y_train, non_leaf_considered_leaf = non_leaf_considered_leaf, max_depth=␣
→max_depth))

    #Validation accuracy
    print("Final Validation accuracy: ",predict_new(root, types, X_val, y_val,␣
→non_leaf_considered_leaf = non_leaf_considered_leaf, max_depth= max_depth))

    #Testing accuracy
    print("Final Testing accuracy: ",predict_new(root, types, X_test, y_test,␣
→non_leaf_considered_leaf = non_leaf_considered_leaf, max_depth= max_depth))

    #Plot avg f1_scores for different depth
    plt.figure(figsize=(10,5))
    plt.plot(no_non_leaf_nodes, train_acc, marker='o', markersize=6,␣
→color='blue', label='train accuracy')
    plt.plot(no_non_leaf_nodes, test_acc, marker='o', markersize=6,␣
→color='red', label='test accuracy')
    plt.plot(no_non_leaf_nodes, val_acc, marker='o', markersize=6,␣
→color='green', label='validation accuracy')

    plt.title('accuracy vs non leaf nodes')
    plt.xlabel('non leaf nodes')
    plt.ylabel('accuracy')
    plt.gca().invert_xaxis()   # this line reverses the x-axis
    plt.xticks(no_non_leaf_nodes)
    plt.ylim(0,1.1)
    plt.legend()
    plt.show()
```

```python
[135]: post_pruning(dtree_1h.root, 15)
```

```
Initial validation accuracy: 0.596551724137931
Validation accuracy is 0.596551724137931. node with id:12274 is now a leaf node.
unvisited_non_leaf_nodes:218
Validation accuracy is 0.596551724137931. node with id:23389 is now a leaf node.
unvisited_non_leaf_nodes:214
Validation accuracy is 0.596551724137931. node with id:24902 is now a leaf node.
unvisited_non_leaf_nodes:206
Validation accuracy is 0.596551724137931. node with id:16578 is now a leaf node.
unvisited_non_leaf_nodes:205
Final Training accuracy:  0.5934585409480005
Final Validation accuracy:  0.596551724137931
Final Testing accuracy:  0.5594622543950362
```


accuracy vs non leaf nodes
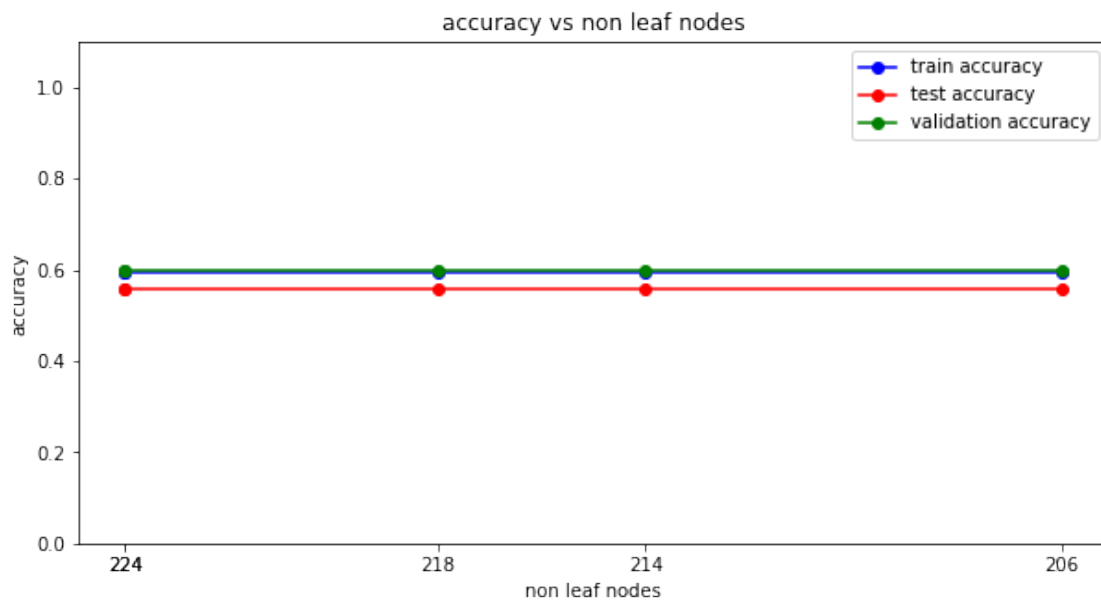
```
[136]:  post_pruning(dtree_1h.root, 25)
```

```
Initial validation accuracy: 0.6183908045977011
Validation accuracy is 0.6206896551724138. node with id:9341 is now a leaf node.
unvisited_non_leaf_nodes:780
Validation accuracy is 0.6218390804597701. node with id:25111 is now a leaf
node. unvisited_non_leaf_nodes:765
Validation accuracy is 0.6218390804597701. node with id:8247 is now a leaf node.
unvisited_non_leaf_nodes:764
Validation accuracy is 0.6218390804597701. node with id:6013 is now a leaf node.
unvisited_non_leaf_nodes:762
Validation accuracy is 0.6218390804597701. node with id:24484 is now a leaf
node. unvisited_non_leaf_nodes:753
Validation accuracy is 0.6218390804597701. node with id:23006 is now a leaf
node. unvisited_non_leaf_nodes:749
```

```
Final Training accuracy:  0.6191388782419829
Final Validation accuracy:  0.6218390804597701
Final Testing accuracy:  0.578076525336091
```


accuracy vs non leaf nodes
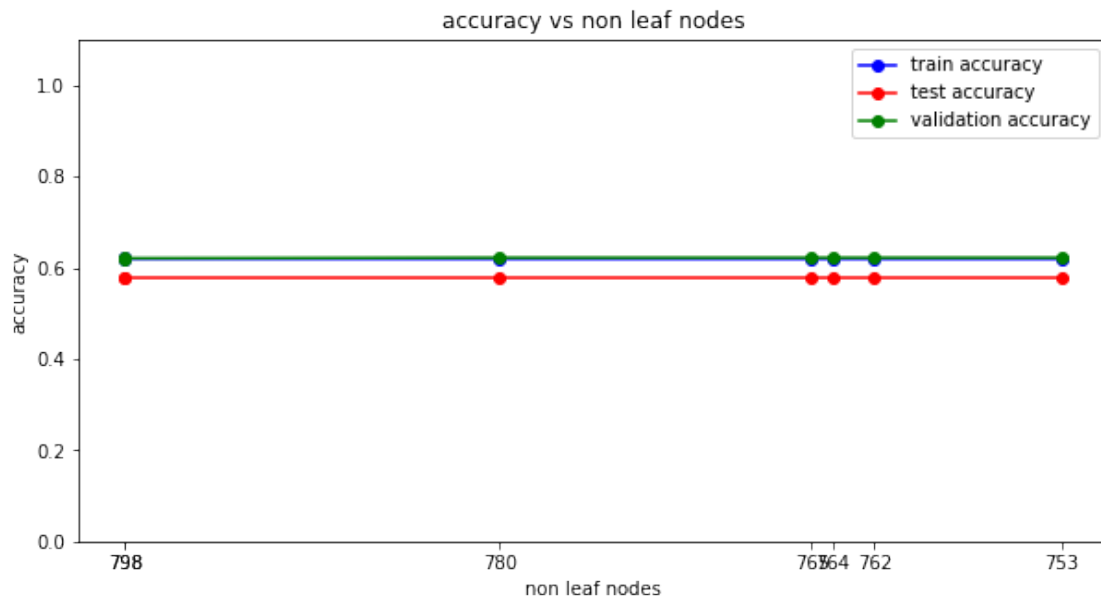
```
[137]:  post_pruning(dtree_1h.root, 35)
```

```
Initial validation accuracy: 0.603448275862069
Validation accuracy is 0.6114942528735632. node with id:4434 is now a leaf node.
unvisited_non_leaf_nodes:2362
Validation accuracy is 0.6183908045977011. node with id:6605 is now a leaf node.
unvisited_non_leaf_nodes:2356
Validation accuracy is 0.6241379310344828. node with id:22999 is now a leaf
node. unvisited_non_leaf_nodes:2331
Validation accuracy is 0.6275862068965518. node with id:16265 is now a leaf
node. unvisited_non_leaf_nodes:2301
Validation accuracy is 0.6298850574712643. node with id:9342 is now a leaf node.
unvisited_non_leaf_nodes:2231
Validation accuracy is 0.632183908045977. node with id:11563 is now a leaf node.
unvisited_non_leaf_nodes:2148
Validation accuracy is 0.6333333333333333. node with id:3907 is now a leaf node.
unvisited_non_leaf_nodes:2143
Validation accuracy is 0.6344827586206897. node with id:7926 is now a leaf node.
unvisited_non_leaf_nodes:2137
Validation accuracy is 0.635632183908046. node with id:4151 is now a leaf node.
unvisited_non_leaf_nodes:2110
Validation accuracy is 0.6367816091954023. node with id:33 is now a leaf node.
unvisited_non_leaf_nodes:2107
Validation accuracy is 0.6379310344827587. node with id:23400 is now a leaf
```

node. unvisited_non_leaf_nodes:2072
Validation accuracy is 0.6379310344827587. node with id:20753 is now a leaf
node. unvisited_non_leaf_nodes:2018
Validation accuracy is 0.6379310344827587. node with id:7770 is now a leaf node.
unvisited_non_leaf_nodes:2014
Validation accuracy is 0.6379310344827587. node with id:26653 is now a leaf
node. unvisited_non_leaf_nodes:1978
Final Training accuracy: 0.6331927941740131
Final Validation accuracy: 0.6379310344827587
Final Testing accuracy: 0.5801447776628749
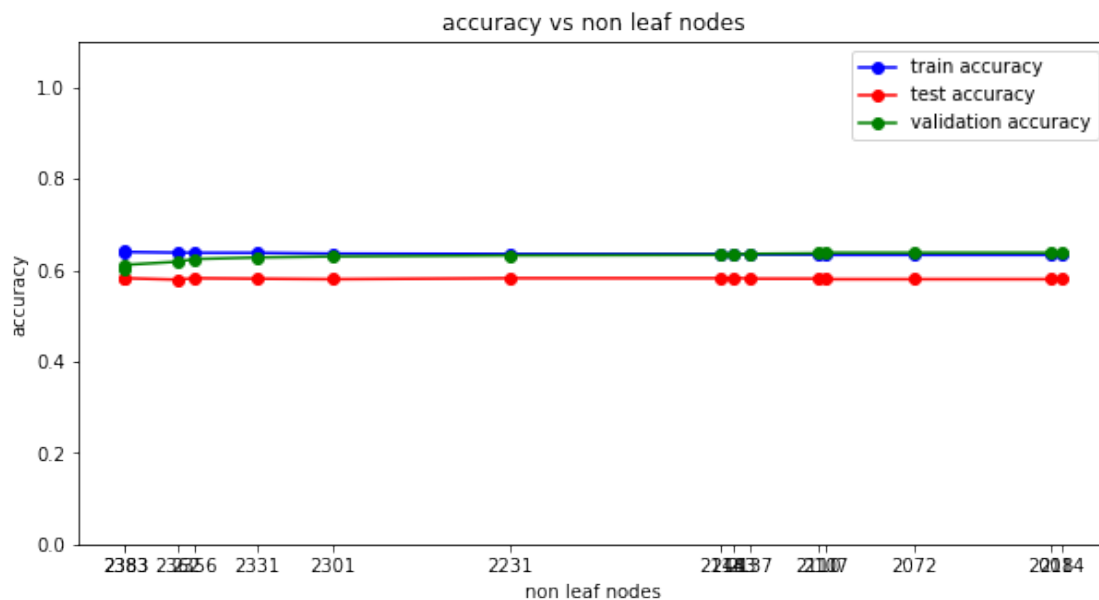
[138]: post_pruning(dtree_1h.root, 45)

Initial validation accuracy: 0.6091954022988506
Validation accuracy is 0.6195402298850575. node with id:20741 is now a leaf
node. unvisited_non_leaf_nodes:6033
Validation accuracy is 0.6275862068965518. node with id:4426 is now a leaf node.
unvisited_non_leaf_nodes:5801
Validation accuracy is 0.635632183908046. node with id:15047 is now a leaf node.
unvisited_non_leaf_nodes:5491
Validation accuracy is 0.6413793103448275. node with id:31 is now a leaf node.
unvisited_non_leaf_nodes:5390
Validation accuracy is 0.6459770114942529. node with id:25954 is now a leaf
node. unvisited_non_leaf_nodes:5377
Validation accuracy is 0.6505747126436782. node with id:12637 is now a leaf
node. unvisited_non_leaf_nodes:5054
Validation accuracy is 0.6528735632183909. node with id:7756 is now a leaf node.
unvisited_non_leaf_nodes:4950

Validation accuracy is 0.6551724137931034. node with id:1178 is now a leaf node. unvisited_non_leaf_nodes:4921
Validation accuracy is 0.6574712643678161. node with id:11166 is now a leaf node. unvisited_non_leaf_nodes:4914
Validation accuracy is 0.6597701149425287. node with id:11562 is now a leaf node. unvisited_non_leaf_nodes:4750
Validation accuracy is 0.6609195402298851. node with id:10783 is now a leaf node. unvisited_non_leaf_nodes:4721
Validation accuracy is 0.6620689655172414. node with id:23399 is now a leaf node. unvisited_non_leaf_nodes:4542
Validation accuracy is 0.6632183908045977. node with id:19524 is now a leaf node. unvisited_non_leaf_nodes:4487
Validation accuracy is 0.664367816091954. node with id:26309 is now a leaf node. unvisited_non_leaf_nodes:4468
Validation accuracy is 0.6655172413793103. node with id:10400 is now a leaf node. unvisited_non_leaf_nodes:4452
Validation accuracy is 0.6666666666666666. node with id:1461 is now a leaf node. unvisited_non_leaf_nodes:4447
Validation accuracy is 0.667816091954023. node with id:3695 is now a leaf node. unvisited_non_leaf_nodes:4358
Validation accuracy is 0.66896555172413793. node with id:2349 is now a leaf node. unvisited_non_leaf_nodes:4355
Validation accuracy is 0.6701149425287356. node with id:7450 is now a leaf node. unvisited_non_leaf_nodes:4343
Validation accuracy is 0.671264367816092. node with id:2634 is now a leaf node. unvisited_non_leaf_nodes:4342
Validation accuracy is 0.6724137931034483. node with id:6482 is now a leaf node. unvisited_non_leaf_nodes:4323
Validation accuracy is 0.6735632183908046. node with id:6804 is now a leaf node. unvisited_non_leaf_nodes:4317
Validation accuracy is 0.674712643678161. node with id:17438 is now a leaf node. unvisited_non_leaf_nodes:4316
Validation accuracy is 0.6758620689655173. node with id:17116 is now a leaf node. unvisited_non_leaf_nodes:4311
Validation accuracy is 0.6758620689655173. node with id:3635 is now a leaf node. unvisited_non_leaf_nodes:4306
Validation accuracy is 0.6758620689655173. node with id:20311 is now a leaf node. unvisited_non_leaf_nodes:4305
Validation accuracy is 0.6758620689655173. node with id:10760 is now a leaf node. unvisited_non_leaf_nodes:4301
Final Training accuracy: 0.6681998211319791
Final Validation accuracy: 0.6758620689655173
Final Testing accuracy: 0.5853154084798345

accuracy vs non leaf nodes
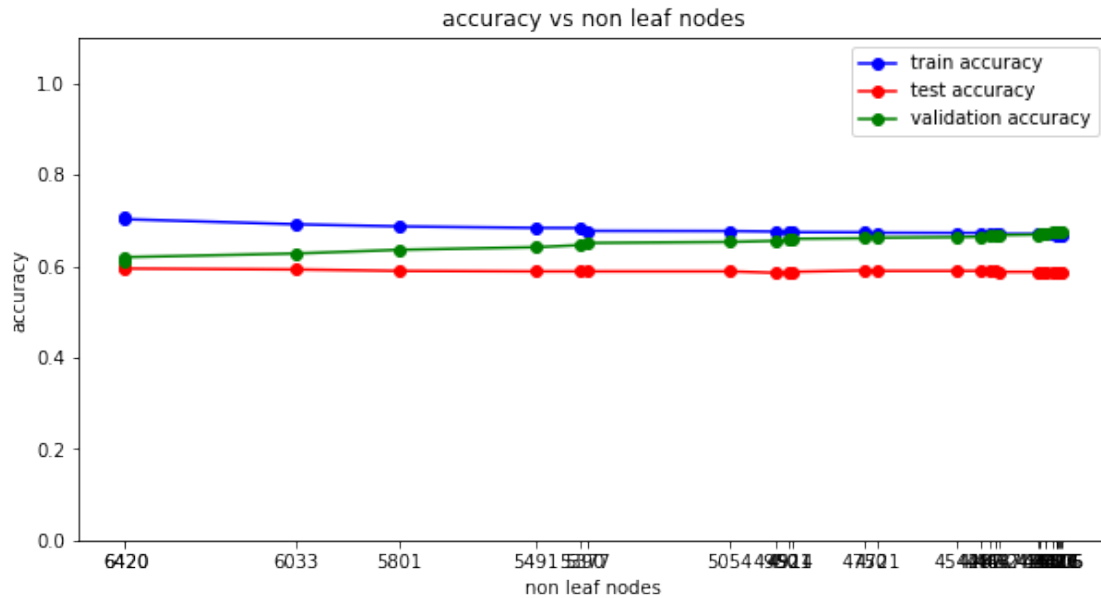
0.0.1 Decision tree using scikit learn

```
[6]: X_train,y_train = get_np_array('../Data/train.csv', encoding="onehot")
     X_test, y_test = get_np_array("../Data/test.csv", encoding="onehot")
     X_val, y_val = get_np_array("../Data/val.csv", encoding="onehot")
```

Keeping criterion as entropy

```
[7]: clf = tree.DecisionTreeClassifier(criterion="entropy")
     clf = clf.fit(X_train, y_train)
```

```
[8]: y_train_pred = clf.predict(X_train)
     y_val_pred = clf.predict(X_val)
     print(f"Training accuracy: {accuracy_score(y_train, y_train_pred)}")
     print(f"Validation accuracy: {accuracy_score(y_val, y_val_pred)}")
```

```
Training accuracy: 1.0
Validation accuracy: 0.6183908045977011
```

(i) Varying the max_depth = {15,25,35,45} and reporting the train and test accuracies

```
[9]: max_depths = [15,25,35,45]
     train_accuracy = []
     test_accuracy = []
     for max_depth in max_depths:
         clf = tree.DecisionTreeClassifier(criterion="entropy", max_depth=max_depth)
         clf = clf.fit(X_train, y_train)
         y_train_pred = clf.predict(X_train)
```

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```
    y_val_pred = clf.predict(X_val)
    y_test_pred = clf.predict(X_test)

    train_acc = accuracy_score(y_train, y_train_pred)
    test_acc = accuracy_score(y_test, y_test_pred)
    print(f"max_depth used is {max_depth}")
    print(f"Training accuracy: {train_acc}")
    print(f"Validation accuracy: {accuracy_score(y_val, y_val_pred)}")
    print(f"Testing accuracy: {test_acc}\n")
    train_accuracy.append(train_acc)
    test_accuracy.append(test_acc)
```

```
max_depth used is 15
Training accuracy: 0.7129168263702568
Validation accuracy: 0.5850574712643678
Testing accuracy: 0.6070320579110652

max_depth used is 25
Training accuracy: 0.854733614411652
Validation accuracy: 0.6126436781609196
Testing accuracy: 0.6411582213029989

max_depth used is 35
Training accuracy: 0.9442953877603169
Validation accuracy: 0.6091954022988506
Testing accuracy: 0.6535677352637022

max_depth used is 45
Training accuracy: 0.9950172479877347
Validation accuracy: 0.6275862068965518
Testing accuracy: 0.640124095139607
```

[11]:
```python
#Plot the train_acc and test_acc for various max depths
plt.figure(figsize=(10,5))
plt.plot(max_depths, train_accuracy, marker='o', markersize=6, color='blue',
 ↪label='train accuracy')
plt.plot(max_depths, test_accuracy, marker='o', markersize=6, color='red',
 ↪label='test accuracy')

plt.title('accuracy vs max depth')
plt.xlabel('max depth')
plt.ylabel('accuracy')
plt.xticks(max_depths)
plt.ylim(0,1.1)
plt.legend()
plt.show()
```

accuracy vs max depth
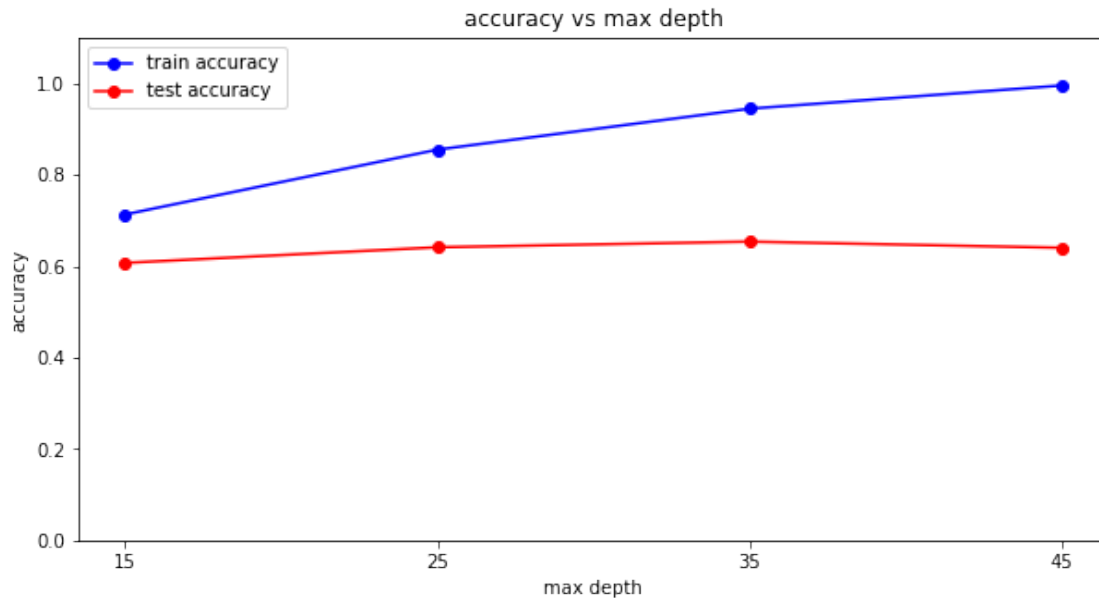
Running the decision tree on the best value of max_depth obtained using validation accuracy

```
[12]: clf = tree.DecisionTreeClassifier(criterion="entropy", max_depth=45)
      clf = clf.fit(X_train, y_train)
      y_train_pred = clf.predict(X_train)
      y_test_pred = clf.predict(X_test)
      print(f"max_depth used is 45")
      print(f"Training accuracy: {accuracy_score(y_train, y_train_pred)}")
      print(f"Testing accuracy: {accuracy_score(y_test, y_test_pred)}\n")
```

```
max_depth used is 45
Training accuracy: 0.9951450108598441
Testing accuracy: 0.6349534643226473
```

(ii) Varying the ccp_alpha = {0.001, 0.01, 0.1, 0.2} and reporting the train and test accuracies

```
[13]: ccp_alphas = [0.001, 0.01, 0.1, 0.2]
      train_accuracy = []
      test_accuracy = []
      for ccp_alpha in ccp_alphas:
          clf = tree.DecisionTreeClassifier(criterion="entropy", ccp_alpha=ccp_alpha)
          clf = clf.fit(X_train, y_train)
          y_train_pred = clf.predict(X_train)
          y_val_pred = clf.predict(X_val)
          y_test_pred = clf.predict(X_test)
```

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```python
    train_acc = accuracy_score(y_train, y_train_pred)
    test_acc = accuracy_score(y_test, y_test_pred)
    print(f"ccp_alpha used is {ccp_alpha}")
    print(f"Training accuracy: {train_acc}")
    print(f"Validation accuracy: {accuracy_score(y_val, y_val_pred)}")
    print(f"Testing accuracy: {test_acc}\n")
    train_accuracy.append(train_acc)
    test_accuracy.append(test_acc)
```

```
ccp_alpha used is 0.001
Training accuracy: 0.6894084579021337
Validation accuracy: 0.632183908045977
Testing accuracy: 0.6628748707342296

ccp_alpha used is 0.01
Training accuracy: 0.5344320940334739
Validation accuracy: 0.5
Testing accuracy: 0.5180972078593589

ccp_alpha used is 0.1
Training accuracy: 0.5033857161108982
Validation accuracy: 0.4735632183908046
Testing accuracy: 0.4963805584281282

ccp_alpha used is 0.2
Training accuracy: 0.5033857161108982
Validation accuracy: 0.4735632183908046
Testing accuracy: 0.4963805584281282
```

```python
[14]: #Plot the train_acc and test_acc for various ccp_alphas
      plt.figure(figsize=(10,5))
      plt.plot(ccp_alphas, train_accuracy, marker='o', markersize=6, color='blue',
       ↪label='train accuracy')
      plt.plot(ccp_alphas, test_accuracy, marker='o', markersize=6, color='red',
       ↪label='test accuracy')

      plt.title('accuracy vs ccp_alpha')
      plt.xlabel('ccp_alpha')
      plt.ylabel('accuracy')
      plt.xticks(ccp_alphas)
      plt.ylim(0,1.1)
      plt.legend()
      plt.show()
```

accuracy vs ccp_alpha
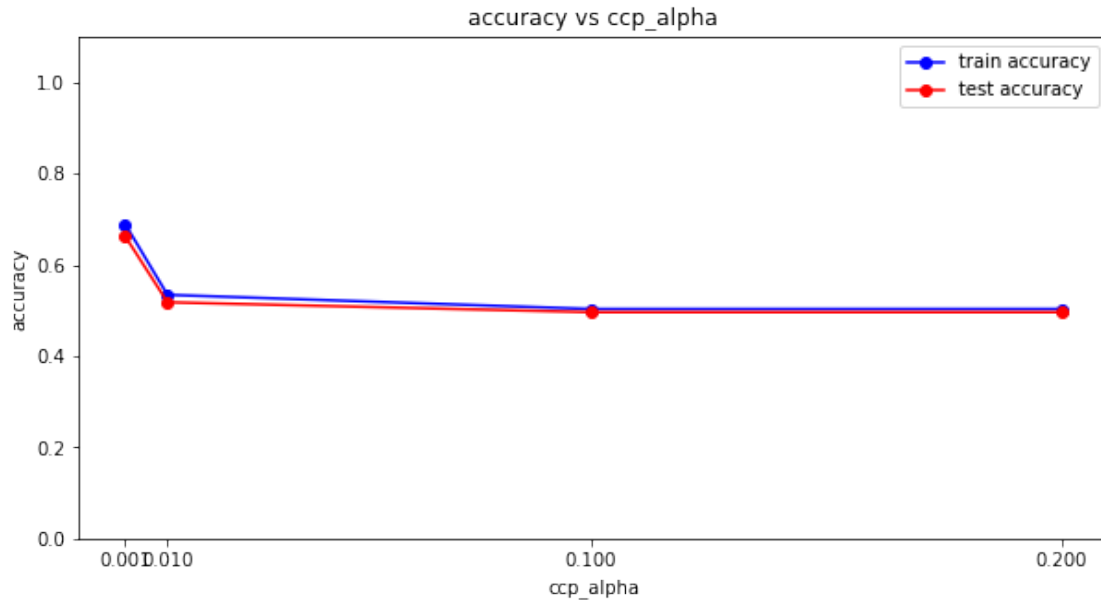
Running the decision tree on the best value of ccp_alpha obtained using validation accuracy

```
[15]: clf = tree.DecisionTreeClassifier(criterion="entropy", ccp_alpha=0.001)
      clf = clf.fit(X_train, y_train)
      y_train_pred = clf.predict(X_train)
      y_val_pred = clf.predict(X_val)
      y_test_pred = clf.predict(X_test)
      print(f"ccp_alpha used is 0.001")
      print(f"Training accuracy: {accuracy_score(y_train, y_train_pred)}")
      print(f"Testing accuracy: {accuracy_score(y_test, y_test_pred)}\n")
```

```
ccp_alpha used is 0.001
Training accuracy: 0.6894084579021337
Testing accuracy: 0.6628748707342296
```

Random forests

```
[17]: X_train,y_train = get_np_array('../Data/train.csv', encoding="onehot")
      X_test, y_test = get_np_array("../Data/test.csv", encoding="onehot")
      X_val, y_val = get_np_array("../Data/val.csv", encoding="onehot")
```

```
[24]: best_oob_score_ = 0
      best_n_estimators = None
      best_max_features = None
      best_min_samples_split = None
```

```python
for n_estimators in [50, 150, 250, 350]:
    for max_features in [0.1, 0.3, 0.5, 0.7, 0.9, 1.0]:
        for min_samples_split in [2, 4, 6, 8, 10]:
            print(f"Parameters->(n_estimators={n_estimators},
→max_features={max_features}, min_samples_split={min_samples_split})")
            clf = RandomForestClassifier(n_estimators = n_estimators,
→max_features=max_features, min_samples_split=min_samples_split,criterion =
→"entropy", oob_score=True)
            clf.fit(X_train, y_train.ravel())
            y_val_pred = clf.predict(X_val)
            print(f"validation accuracy: {accuracy_score(y_val.ravel(),
→y_val_pred)}")
            print("OOB(out of bag) accuracy: ",clf.oob_score_)
            print("\n")

            #update best
            if clf.oob_score_ > best_oob_score_:
                best_oob_score_ = clf.oob_score_
                best_n_estimators = n_estimators
                best_max_features = max_features
                best_min_samples_split = min_samples_split
```

Parameters->(n_estimators=50, max_features=0.1, min_samples_split=2)
validation accuracy: 0.6850574712643678
OOB(out of bag) accuracy: 0.6804650568544781

Parameters->(n_estimators=50, max_features=0.1, min_samples_split=4)
validation accuracy: 0.6793103448275862
OOB(out of bag) accuracy: 0.6794429538776031

Parameters->(n_estimators=50, max_features=0.1, min_samples_split=6)
validation accuracy: 0.6931034482758621
OOB(out of bag) accuracy: 0.6949022614028363

Parameters->(n_estimators=50, max_features=0.1, min_samples_split=8)
validation accuracy: 0.696551724137931
OOB(out of bag) accuracy: 0.691963715344321

Parameters->(n_estimators=50, max_features=0.1, min_samples_split=10)
validation accuracy: 0.6850574712643678
OOB(out of bag) accuracy: 0.6821259741918998

```
Parameters->(n_estimators=50, max_features=0.3, min_samples_split=2)
validation accuracy: 0.6885057471264368
OOB(out of bag) accuracy:  0.6927302925769772


Parameters->(n_estimators=50, max_features=0.3, min_samples_split=4)
validation accuracy: 0.6896551724137931
OOB(out of bag) accuracy:  0.6974575188450236


Parameters->(n_estimators=50, max_features=0.3, min_samples_split=6)
validation accuracy: 0.6827586206896552
OOB(out of bag) accuracy:  0.6914526638558834


Parameters->(n_estimators=50, max_features=0.3, min_samples_split=8)
validation accuracy: 0.7
OOB(out of bag) accuracy:  0.6984796218218986


Parameters->(n_estimators=50, max_features=0.3, min_samples_split=10)
validation accuracy: 0.696551724137931
OOB(out of bag) accuracy:  0.6982240960776799


Parameters->(n_estimators=50, max_features=0.5, min_samples_split=2)
validation accuracy: 0.6896551724137931
OOB(out of bag) accuracy:  0.6992461990545548


Parameters->(n_estimators=50, max_features=0.5, min_samples_split=4)
validation accuracy: 0.6931034482758621
OOB(out of bag) accuracy:  0.6924747668327584


Parameters->(n_estimators=50, max_features=0.5, min_samples_split=6)
validation accuracy: 0.6885057471264368
OOB(out of bag) accuracy:  0.6992461990545548


Parameters->(n_estimators=50, max_features=0.5, min_samples_split=8)
validation accuracy: 0.7068965517241379
OOB(out of bag) accuracy:  0.7052510540436949


Parameters->(n_estimators=50, max_features=0.5, min_samples_split=10)
validation accuracy: 0.6885057471264368
OOB(out of bag) accuracy:  0.7075507857416635
```

```
Parameters->(n_estimators=50, max_features=0.7, min_samples_split=2)
validation accuracy: 0.6816091954022988
OOB(out of bag) accuracy:  0.7007793535198671


Parameters->(n_estimators=50, max_features=0.7, min_samples_split=4)
validation accuracy: 0.6919540229885057
OOB(out of bag) accuracy:  0.700396064903539


Parameters->(n_estimators=50, max_features=0.7, min_samples_split=6)
validation accuracy: 0.6931034482758621
OOB(out of bag) accuracy:  0.7048677654273668


Parameters->(n_estimators=50, max_features=0.7, min_samples_split=8)
validation accuracy: 0.7034482758620689
OOB(out of bag) accuracy:  0.7141944550913505


Parameters->(n_estimators=50, max_features=0.7, min_samples_split=10)
validation accuracy: 0.7114942528735633
OOB(out of bag) accuracy:  0.7075507857416635


Parameters->(n_estimators=50, max_features=0.9, min_samples_split=2)
validation accuracy: 0.6954022988505747
OOB(out of bag) accuracy:  0.6996294876708828


Parameters->(n_estimators=50, max_features=0.9, min_samples_split=4)
validation accuracy: 0.6954022988505747
OOB(out of bag) accuracy:  0.7092117030790852


Parameters->(n_estimators=50, max_features=0.9, min_samples_split=6)
validation accuracy: 0.7022988505747126
OOB(out of bag) accuracy:  0.6996294876708828


Parameters->(n_estimators=50, max_features=0.9, min_samples_split=8)
validation accuracy: 0.7091954022988506
OOB(out of bag) accuracy:  0.7055065797879136


Parameters->(n_estimators=50, max_features=0.9, min_samples_split=10)
```

```
validation accuracy: 0.7091954022988506
OOB(out of bag) accuracy:  0.7076785486137729


Parameters->(n_estimators=50, max_features=1.0, min_samples_split=2)
validation accuracy: 0.7126436781609196
OOB(out of bag) accuracy:  0.7044844768110388


Parameters->(n_estimators=50, max_features=1.0, min_samples_split=4)
validation accuracy: 0.6977011494252874
OOB(out of bag) accuracy:  0.7006515906477577


Parameters->(n_estimators=50, max_features=1.0, min_samples_split=6)
validation accuracy: 0.6988505747126437
OOB(out of bag) accuracy:  0.700396064903539


Parameters->(n_estimators=50, max_features=1.0, min_samples_split=8)
validation accuracy: 0.7091954022988506
OOB(out of bag) accuracy:  0.7121502491376006


Parameters->(n_estimators=50, max_features=1.0, min_samples_split=10)
validation accuracy: 0.7045977011494253
OOB(out of bag) accuracy:  0.7079340743579916


Parameters->(n_estimators=150, max_features=0.1, min_samples_split=2)
validation accuracy: 0.6816091954022988
OOB(out of bag) accuracy:  0.6950300242749456


Parameters->(n_estimators=150, max_features=0.1, min_samples_split=4)
validation accuracy: 0.6908045977011494
OOB(out of bag) accuracy:  0.7018014564967421


Parameters->(n_estimators=150, max_features=0.1, min_samples_split=6)
validation accuracy: 0.6919540229885057
OOB(out of bag) accuracy:  0.7043567139389294


Parameters->(n_estimators=150, max_features=0.1, min_samples_split=8)
validation accuracy: 0.6977011494252874
OOB(out of bag) accuracy:  0.7055065797879136
```

```
Parameters->(n_estimators=150, max_features=0.1, min_samples_split=10)
validation accuracy: 0.6885057471264368
OOB(out of bag) accuracy:  0.7001405391593203


Parameters->(n_estimators=150, max_features=0.3, min_samples_split=2)
validation accuracy: 0.6908045977011494
OOB(out of bag) accuracy:  0.7018014564967421


Parameters->(n_estimators=150, max_features=0.3, min_samples_split=4)
validation accuracy: 0.7057471264367816
OOB(out of bag) accuracy:  0.7064009198926792


Parameters->(n_estimators=150, max_features=0.3, min_samples_split=6)
validation accuracy: 0.6954022988505747
OOB(out of bag) accuracy:  0.7102338060559601


Parameters->(n_estimators=150, max_features=0.3, min_samples_split=8)
validation accuracy: 0.6977011494252874
OOB(out of bag) accuracy:  0.7107448575443976


Parameters->(n_estimators=150, max_features=0.3, min_samples_split=10)
validation accuracy: 0.6954022988505747
OOB(out of bag) accuracy:  0.707423022869554


Parameters->(n_estimators=150, max_features=0.5, min_samples_split=2)
validation accuracy: 0.6770114942528735
OOB(out of bag) accuracy:  0.7141944550913505


Parameters->(n_estimators=150, max_features=0.5, min_samples_split=4)
validation accuracy: 0.6942528735632184
OOB(out of bag) accuracy:  0.7170052382777565


Parameters->(n_estimators=150, max_features=0.5, min_samples_split=6)
validation accuracy: 0.7057471264367816
OOB(out of bag) accuracy:  0.7102338060559601


Parameters->(n_estimators=150, max_features=0.5, min_samples_split=8)
validation accuracy: 0.6954022988505747
```

```
OOB(out of bag) accuracy:  0.7173885268940846



Parameters->(n_estimators=150, max_features=0.5, min_samples_split=10)
validation accuracy: 0.7022988505747126
OOB(out of bag) accuracy:  0.7129168263702568



Parameters->(n_estimators=150, max_features=0.7, min_samples_split=2)
validation accuracy: 0.696551724137931
OOB(out of bag) accuracy:  0.7106170946722883



Parameters->(n_estimators=150, max_features=0.7, min_samples_split=4)
validation accuracy: 0.6977011494252874
OOB(out of bag) accuracy:  0.7182828669988501



Parameters->(n_estimators=150, max_features=0.7, min_samples_split=6)
validation accuracy: 0.7034482758620689
OOB(out of bag) accuracy:  0.71227801200971



Parameters->(n_estimators=150, max_features=0.7, min_samples_split=8)
validation accuracy: 0.7011494252873564
OOB(out of bag) accuracy:  0.7154720838124441



Parameters->(n_estimators=150, max_features=0.7, min_samples_split=10)
validation accuracy: 0.7114942528735633
OOB(out of bag) accuracy:  0.7185383927430689



Parameters->(n_estimators=150, max_features=0.9, min_samples_split=2)
validation accuracy: 0.6896551724137931
OOB(out of bag) accuracy:  0.7141944550913505



Parameters->(n_estimators=150, max_features=0.9, min_samples_split=4)
validation accuracy: 0.7011494252873564
OOB(out of bag) accuracy:  0.7133001149865849



Parameters->(n_estimators=150, max_features=0.9, min_samples_split=6)
validation accuracy: 0.7
OOB(out of bag) accuracy:  0.7168774754056472
```

```
Parameters->(n_estimators=150, max_features=0.9, min_samples_split=8)
validation accuracy: 0.7
OOB(out of bag) accuracy:   0.723137856139006


Parameters->(n_estimators=150, max_features=0.9, min_samples_split=10)
validation accuracy: 0.7057471264367816
OOB(out of bag) accuracy:   0.7207103615689281


Parameters->(n_estimators=150, max_features=1.0, min_samples_split=2)
validation accuracy: 0.6988505747126437
OOB(out of bag) accuracy:   0.7173885268940846


Parameters->(n_estimators=150, max_features=1.0, min_samples_split=4)
validation accuracy: 0.6896551724137931
OOB(out of bag) accuracy:   0.7152165580682254


Parameters->(n_estimators=150, max_features=1.0, min_samples_split=6)
validation accuracy: 0.7114942528735633
OOB(out of bag) accuracy:   0.7191772071036157


Parameters->(n_estimators=150, max_features=1.0, min_samples_split=8)
validation accuracy: 0.7114942528735633
OOB(out of bag) accuracy:   0.7184106298709595


Parameters->(n_estimators=150, max_features=1.0, min_samples_split=10)
validation accuracy: 0.7034482758620689
OOB(out of bag) accuracy:   0.7239044333716622


Parameters->(n_estimators=250, max_features=0.1, min_samples_split=2)
validation accuracy: 0.6850574712643678
OOB(out of bag) accuracy:   0.6952855500191645


Parameters->(n_estimators=250, max_features=0.1, min_samples_split=4)
validation accuracy: 0.6781609195402298
OOB(out of bag) accuracy:   0.7002683020314296


Parameters->(n_estimators=250, max_features=0.1, min_samples_split=6)
validation accuracy: 0.6862068965517242
OOB(out of bag) accuracy:   0.7030790852178357
```

```
Parameters->(n_estimators=250, max_features=0.1, min_samples_split=8)
validation accuracy: 0.6919540229885057
OOB(out of bag) accuracy:  0.7079340743579916


Parameters->(n_estimators=250, max_features=0.1, min_samples_split=10)
validation accuracy: 0.6977011494252874
OOB(out of bag) accuracy:  0.7088284144627571


Parameters->(n_estimators=250, max_features=0.3, min_samples_split=2)
validation accuracy: 0.6827586206896552
OOB(out of bag) accuracy:  0.7145777437076786


Parameters->(n_estimators=250, max_features=0.3, min_samples_split=4)
validation accuracy: 0.7011494252873564
OOB(out of bag) accuracy:  0.7135556407308036


Parameters->(n_estimators=250, max_features=0.3, min_samples_split=6)
validation accuracy: 0.7011494252873564
OOB(out of bag) accuracy:  0.7124057748818193


Parameters->(n_estimators=250, max_features=0.3, min_samples_split=8)
validation accuracy: 0.7160919540229885
OOB(out of bag) accuracy:  0.71227801200971


Parameters->(n_estimators=250, max_features=0.3, min_samples_split=10)
validation accuracy: 0.6954022988505747
OOB(out of bag) accuracy:  0.7120224862654913


Parameters->(n_estimators=250, max_features=0.5, min_samples_split=2)
validation accuracy: 0.6942528735632184
OOB(out of bag) accuracy:  0.71227801200971


Parameters->(n_estimators=250, max_features=0.5, min_samples_split=4)
validation accuracy: 0.6954022988505747
OOB(out of bag) accuracy:  0.7180273412546314


Parameters->(n_estimators=250, max_features=0.5, min_samples_split=6)
```

```
validation accuracy: 0.7
OOB(out of bag) accuracy:  0.7208381244410375



Parameters->(n_estimators=250, max_features=0.5, min_samples_split=8)
validation accuracy: 0.7011494252873564
OOB(out of bag) accuracy:  0.7200715472083813



Parameters->(n_estimators=250, max_features=0.5, min_samples_split=10)
validation accuracy: 0.696551724137931
OOB(out of bag) accuracy:  0.7194327328478344



Parameters->(n_estimators=250, max_features=0.7, min_samples_split=2)
validation accuracy: 0.6977011494252874
OOB(out of bag) accuracy:  0.7158553724287722



Parameters->(n_estimators=250, max_features=0.7, min_samples_split=4)
validation accuracy: 0.696551724137931
OOB(out of bag) accuracy:  0.7157276095566628



Parameters->(n_estimators=250, max_features=0.7, min_samples_split=6)
validation accuracy: 0.7011494252873564
OOB(out of bag) accuracy:  0.717516289766194



Parameters->(n_estimators=250, max_features=0.7, min_samples_split=8)
validation accuracy: 0.7022988505747126
OOB(out of bag) accuracy:  0.7189216813593969



Parameters->(n_estimators=250, max_features=0.7, min_samples_split=10)
validation accuracy: 0.7022988505747126
OOB(out of bag) accuracy:  0.7187939184872876



Parameters->(n_estimators=250, max_features=0.9, min_samples_split=2)
validation accuracy: 0.6850574712643678
OOB(out of bag) accuracy:  0.7190494442315063



Parameters->(n_estimators=250, max_features=0.9, min_samples_split=4)
validation accuracy: 0.7011494252873564
OOB(out of bag) accuracy:  0.7172607640219753
```

```
Parameters->(n_estimators=250, max_features=0.9, min_samples_split=6)
validation accuracy: 0.7057471264367816
OOB(out of bag) accuracy:  0.7250542992206465


Parameters->(n_estimators=250, max_features=0.9, min_samples_split=8)
validation accuracy: 0.7
OOB(out of bag) accuracy:  0.7213491759294749


Parameters->(n_estimators=250, max_features=0.9, min_samples_split=10)
validation accuracy: 0.7011494252873564
OOB(out of bag) accuracy:  0.721732464545803


Parameters->(n_estimators=250, max_features=1.0, min_samples_split=2)
validation accuracy: 0.6862068965517242
OOB(out of bag) accuracy:  0.7177718155104127


Parameters->(n_estimators=250, max_features=1.0, min_samples_split=4)
validation accuracy: 0.7068965517241379
OOB(out of bag) accuracy:  0.7198160214641626


Parameters->(n_estimators=250, max_features=1.0, min_samples_split=6)
validation accuracy: 0.7045977011494253
OOB(out of bag) accuracy:  0.7195604957199437


Parameters->(n_estimators=250, max_features=1.0, min_samples_split=8)
validation accuracy: 0.7034482758620689
OOB(out of bag) accuracy:  0.7240321962437716


Parameters->(n_estimators=250, max_features=1.0, min_samples_split=10)
validation accuracy: 0.6988505747126437
OOB(out of bag) accuracy:  0.7258208764533026


Parameters->(n_estimators=350, max_features=0.1, min_samples_split=2)
validation accuracy: 0.6873563218390805
OOB(out of bag) accuracy:  0.6988629104382267


Parameters->(n_estimators=350, max_features=0.1, min_samples_split=4)
validation accuracy: 0.6827586206896552
```

```
OOB(out of bag) accuracy:   0.7030790852178357


Parameters->(n_estimators=350, max_features=0.1, min_samples_split=6)
validation accuracy: 0.6839080459770115
OOB(out of bag) accuracy:   0.7057621055321324


Parameters->(n_estimators=350, max_features=0.1, min_samples_split=8)
validation accuracy: 0.6919540229885057
OOB(out of bag) accuracy:   0.7099782803117414


Parameters->(n_estimators=350, max_features=0.1, min_samples_split=10)
validation accuracy: 0.7057471264367816
OOB(out of bag) accuracy:   0.7058898684042417


Parameters->(n_estimators=350, max_features=0.3, min_samples_split=2)
validation accuracy: 0.6942528735632184
OOB(out of bag) accuracy:   0.7120224862654913


Parameters->(n_estimators=350, max_features=0.3, min_samples_split=4)
validation accuracy: 0.6896551724137931
OOB(out of bag) accuracy:   0.7134278778586942


Parameters->(n_estimators=350, max_features=0.3, min_samples_split=6)
validation accuracy: 0.7011494252873564
OOB(out of bag) accuracy:   0.7163664239172096


Parameters->(n_estimators=350, max_features=0.3, min_samples_split=8)
validation accuracy: 0.6977011494252874
OOB(out of bag) accuracy:   0.7111281461607257


Parameters->(n_estimators=350, max_features=0.3, min_samples_split=10)
validation accuracy: 0.7045977011494253
OOB(out of bag) accuracy:   0.713683403602913


Parameters->(n_estimators=350, max_features=0.5, min_samples_split=2)
validation accuracy: 0.6908045977011494
OOB(out of bag) accuracy:   0.715088795196116
```

```
Parameters->(n_estimators=350, max_features=0.5, min_samples_split=4)
validation accuracy: 0.6942528735632184
OOB(out of bag) accuracy:  0.7189216813593969


Parameters->(n_estimators=350, max_features=0.5, min_samples_split=6)
validation accuracy: 0.6954022988505747
OOB(out of bag) accuracy:  0.7176440526383033


Parameters->(n_estimators=350, max_features=0.5, min_samples_split=8)
validation accuracy: 0.7011494252873564
OOB(out of bag) accuracy:  0.7203270729526


Parameters->(n_estimators=350, max_features=0.5, min_samples_split=10)
validation accuracy: 0.7068965517241379
OOB(out of bag) accuracy:  0.7186661556151782


Parameters->(n_estimators=350, max_features=0.7, min_samples_split=2)
validation accuracy: 0.6919540229885057
OOB(out of bag) accuracy:  0.7181551041267408


Parameters->(n_estimators=350, max_features=0.7, min_samples_split=4)
validation accuracy: 0.7011494252873564
OOB(out of bag) accuracy:  0.7173885268940846


Parameters->(n_estimators=350, max_features=0.7, min_samples_split=6)
validation accuracy: 0.7
OOB(out of bag) accuracy:  0.7212214130573655


Parameters->(n_estimators=350, max_features=0.7, min_samples_split=8)
validation accuracy: 0.7068965517241379
OOB(out of bag) accuracy:  0.7218602274179123


Parameters->(n_estimators=350, max_features=0.7, min_samples_split=10)
validation accuracy: 0.7011494252873564
OOB(out of bag) accuracy:  0.7209658873131468


Parameters->(n_estimators=350, max_features=0.9, min_samples_split=2)
validation accuracy: 0.6919540229885057
OOB(out of bag) accuracy:  0.7177718155104127
```

```
Parameters->(n_estimators=350, max_features=0.9, min_samples_split=4)
validation accuracy: 0.6977011494252874
OOB(out of bag) accuracy:  0.7205825986968187


Parameters->(n_estimators=350, max_features=0.9, min_samples_split=6)
validation accuracy: 0.6988505747126437
OOB(out of bag) accuracy:  0.7196882585920531


Parameters->(n_estimators=350, max_features=0.9, min_samples_split=8)
validation accuracy: 0.7034482758620689
OOB(out of bag) accuracy:  0.7222435160342404


Parameters->(n_estimators=350, max_features=0.9, min_samples_split=10)
validation accuracy: 0.696551724137931
OOB(out of bag) accuracy:  0.7221157531621311


Parameters->(n_estimators=350, max_features=1.0, min_samples_split=2)
validation accuracy: 0.6827586206896552
OOB(out of bag) accuracy:  0.717899578382522


Parameters->(n_estimators=350, max_features=1.0, min_samples_split=4)
validation accuracy: 0.7022988505747126
OOB(out of bag) accuracy:  0.7224990417784591


Parameters->(n_estimators=350, max_features=1.0, min_samples_split=6)
validation accuracy: 0.7034482758620689
OOB(out of bag) accuracy:  0.7216047016736936


Parameters->(n_estimators=350, max_features=1.0, min_samples_split=8)
validation accuracy: 0.6988505747126437
OOB(out of bag) accuracy:  0.7203270729526


Parameters->(n_estimators=350, max_features=1.0, min_samples_split=10)
validation accuracy: 0.6988505747126437
OOB(out of bag) accuracy:  0.7242877219879903
```

Running the random forest using optimal hyperparameters obtained based on OOB score

```python
print("Optimal parameters based on OOB score:")
print(f"best_oob_score_:{best_oob_score_}")
print(f"best_n_estimators:{best_n_estimators}")
print(f"best_max_features:{best_max_features}")
print(f"best_min_samples_split:{best_min_samples_split}")

clf = RandomForestClassifier(n_estimators = best_n_estimators, max_features =
    best_max_features, min_samples_split = best_min_samples_split,criterion =
    "entropy", oob_score=True)
clf.fit(X_train, y_train.ravel())
y_train_pred = clf.predict(X_train)
y_val_pred = clf.predict(X_val)
y_test_pred = clf.predict(X_test)
print(f"Training accuracy: {accuracy_score(y_train.ravel(), y_train_pred)}")
print(f"Validation accuracy: {accuracy_score(y_val.ravel(), y_val_pred)}")
print(f"Testing accuracy: {accuracy_score(y_test.ravel(), y_test_pred)}")
print("OOB(out of bag) accuracy: ",clf.oob_score_)
```

```
Optimal parameters based on OOB score:
best_oob_score_:0.7258208764533026
best_n_estimators:250
best_max_features:1.0
best_min_samples_split:10
Training accuracy: 0.9814743835441421
Validation accuracy: 0.7045977011494253
Testing accuracy: 0.7249224405377456
OOB(out of bag) accuracy:  0.7199437843362719
```

Grid search to find optimal hyperparameters

```python
#making the instance
model = RandomForestClassifier()

#Hyper Parameters Set
params = {
    'n_estimators': [50, 150, 250, 350],
    'max_features': [0.1, 0.3, 0.5, 0.7, 0.9, 1.0],
    'min_samples_split': [2, 4, 6, 8, 10],
    'criterion' :['entropy'],
    'oob_score': [True],

}

grid = GridSearchCV(estimator=model, param_grid=params, verbose=2)

# Fit the grid search to the data and find best hyperparameters
```

```
grid.fit(X_train, y_train.ravel())
```

```
Fitting 5 folds for each of 120 candidates, totalling 600 fits
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=50, oob_score=True; total time=   0.4s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=50, oob_score=True; total time=   0.4s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=50, oob_score=True; total time=   0.4s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=50, oob_score=True; total time=   0.4s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=50, oob_score=True; total time=   0.4s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=150, oob_score=True; total time=   1.4s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=150, oob_score=True; total time=   1.3s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=150, oob_score=True; total time=   1.3s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=150, oob_score=True; total time=   1.3s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=150, oob_score=True; total time=   1.4s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=250, oob_score=True; total time=   2.2s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=250, oob_score=True; total time=   2.1s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=250, oob_score=True; total time=   2.1s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=250, oob_score=True; total time=   2.1s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=250, oob_score=True; total time=   2.1s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=350, oob_score=True; total time=   3.0s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=350, oob_score=True; total time=   3.0s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=350, oob_score=True; total time=   3.0s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=350, oob_score=True; total time=   3.0s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=2,
n_estimators=350, oob_score=True; total time=   3.0s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=4,
n_estimators=50, oob_score=True; total time=   0.4s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=4,
n_estimators=50, oob_score=True; total time=   0.4s
```

```
[CV] END criterion=entropy, max_features=0.1, min_samples_split=4,
n_estimators=50, oob_score=True; total time=    0.4s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=4,
n_estimators=50, oob_score=True; total time=    0.4s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=4,
n_estimators=50, oob_score=True; total time=    0.4s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=4,
n_estimators=150, oob_score=True; total time=    1.2s
[CV] END criterion=entropy, max_features=0.1, min_samples_split=4,
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```

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```

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```

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```

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[CV] END criterion=entropy, max_features=0.3, min_samples_split=10,
n_estimators=50, oob_score=True; total time=   0.7s
[CV] END criterion=entropy, max_features=0.3, min_samples_split=10,
n_estimators=50, oob_score=True; total time=   0.7s
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n_estimators=150, oob_score=True; total time=   2.2s
[CV] END criterion=entropy, max_features=0.3, min_samples_split=10,
n_estimators=150, oob_score=True; total time=   2.2s
[CV] END criterion=entropy, max_features=0.3, min_samples_split=10,
n_estimators=150, oob_score=True; total time=   2.1s
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n_estimators=150, oob_score=True; total time=   2.2s
```

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n_estimators=250, oob_score=True; total time=   3.7s
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n_estimators=250, oob_score=True; total time=   3.6s
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[CV] END criterion=entropy, max_features=0.5, min_samples_split=2,
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```

```
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[CV] END criterion=entropy, max_features=0.5, min_samples_split=4,
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[CV] END criterion=entropy, max_features=0.5, min_samples_split=4,
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[CV] END criterion=entropy, max_features=0.5, min_samples_split=4,
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[CV] END criterion=entropy, max_features=0.5, min_samples_split=4,
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n_estimators=350, oob_score=True; total time=   8.0s
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```

```
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```

```
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```

```
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```

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```

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n_estimators=350, oob_score=True; total time=   10.4s
```

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```

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```

```
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```

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```

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```

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n_estimators=350, oob_score=True; total time=  12.5s
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n_estimators=350, oob_score=True; total time=  12.6s
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n_estimators=350, oob_score=True; total time=  12.3s
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[CV] END criterion=entropy, max_features=1.0, min_samples_split=2,
n_estimators=50, oob_score=True; total time=   2.1s
```

```
[CV] END criterion=entropy, max_features=1.0, min_samples_split=2,
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n_estimators=250, oob_score=True; total time=  10.2s
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```

```
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[CV] END criterion=entropy, max_features=1.0, min_samples_split=6,
n_estimators=50, oob_score=True; total time=   2.0s
[CV] END criterion=entropy, max_features=1.0, min_samples_split=6,
n_estimators=50, oob_score=True; total time=   2.0s
[CV] END criterion=entropy, max_features=1.0, min_samples_split=6,
n_estimators=50, oob_score=True; total time=   2.1s
[CV] END criterion=entropy, max_features=1.0, min_samples_split=6,
n_estimators=150, oob_score=True; total time=   6.2s
[CV] END criterion=entropy, max_features=1.0, min_samples_split=6,
n_estimators=150, oob_score=True; total time=   6.2s
[CV] END criterion=entropy, max_features=1.0, min_samples_split=6,
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[CV] END criterion=entropy, max_features=1.0, min_samples_split=6,
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[CV] END criterion=entropy, max_features=1.0, min_samples_split=6,
n_estimators=150, oob_score=True; total time=   6.2s
```

```
[CV] END criterion=entropy, max_features=1.0, min_samples_split=6,
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n_estimators=250, oob_score=True; total time=   10.0s
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n_estimators=250, oob_score=True; total time=   10.0s
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n_estimators=250, oob_score=True; total time=   10.2s
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n_estimators=350, oob_score=True; total time=   14.2s
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n_estimators=350, oob_score=True; total time=   14.9s
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n_estimators=50, oob_score=True; total time=    2.0s
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n_estimators=50, oob_score=True; total time=    2.1s
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n_estimators=150, oob_score=True; total time=    6.0s
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n_estimators=150, oob_score=True; total time=    6.4s
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[CV] END criterion=entropy, max_features=1.0, min_samples_split=8,
n_estimators=250, oob_score=True; total time=    9.8s
```

```
[CV] END criterion=entropy, max_features=1.0, min_samples_split=8,
n_estimators=250, oob_score=True; total time=   10.1s
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n_estimators=350, oob_score=True; total time=   14.3s
[CV] END criterion=entropy, max_features=1.0, min_samples_split=8,
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[CV] END criterion=entropy, max_features=1.0, min_samples_split=10,
n_estimators=50, oob_score=True; total time=    2.0s
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n_estimators=150, oob_score=True; total time=    5.8s
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n_estimators=250, oob_score=True; total time=   10.3s
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n_estimators=250, oob_score=True; total time=    9.9s
[CV] END criterion=entropy, max_features=1.0, min_samples_split=10,
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[CV] END criterion=entropy, max_features=1.0, min_samples_split=10,
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[CV] END criterion=entropy, max_features=1.0, min_samples_split=10,
n_estimators=350, oob_score=True; total time=   14.2s
[CV] END criterion=entropy, max_features=1.0, min_samples_split=10,
n_estimators=350, oob_score=True; total time=   14.5s
[CV] END criterion=entropy, max_features=1.0, min_samples_split=10,
n_estimators=350, oob_score=True; total time=   13.7s
```

```
[CV] END criterion=entropy, max_features=1.0, min_samples_split=10,
n_estimators=350, oob_score=True; total time=  13.8s
[CV] END criterion=entropy, max_features=1.0, min_samples_split=10,
n_estimators=350, oob_score=True; total time=  14.5s
```

[26]:
```
GridSearchCV(estimator=RandomForestClassifier(),
             param_grid={'criterion': ['entropy'],
                         'max_features': [0.1, 0.3, 0.5, 0.7, 0.9, 1.0],
                         'min_samples_split': [2, 4, 6, 8, 10],
                         'n_estimators': [50, 150, 250, 350],
                         'oob_score': [True]},
             verbose=2)
```

Running the random forest with best hyperparameters obtained using grid search

[27]:
```python
# Best parameter after tuning
print("Best parameters: ",grid.best_params_)

# Store the best model for future use
model = grid.best_estimator_

model.fit(X_train, y_train.ravel())
y_train_pred = model.predict(X_train)
y_val_pred = model.predict(X_val)
y_test_pred = model.predict(X_test)
print(f"Training accuracy: {accuracy_score(y_train.ravel(), y_train_pred)}")
print(f"Validation accuracy: {accuracy_score(y_val.ravel(), y_val_pred)}")
print(f"Testing accuracy: {accuracy_score(y_test.ravel(), y_test_pred)}")
print("OOB(out of bag) accuracy: ",model.oob_score_)
```

```
Best parameters:  {'criterion': 'entropy', 'max_features': 0.7,
'min_samples_split': 8, 'n_estimators': 350, 'oob_score': True}
Training accuracy: 0.9892679187428134
Validation accuracy: 0.7034482758620689
Testing accuracy: 0.7269906928645294
OOB(out of bag) accuracy:  0.7191772071036157
```

Gradient Boosting Classifier

[37]:
```python
X_train,y_train = get_np_array('../Data/train.csv', encoding="onehot")
X_test, y_test = get_np_array("../Data/test.csv", encoding="onehot")
X_val, y_val = get_np_array("../Data/val.csv", encoding="onehot")
```

Grid search to find optimal hyperparameters

[38]:
```python
#making the instance
model = GradientBoostingClassifier()

#Hyper Parameters Set
```

```python
params = {
    'n_estimators': [50, 100, 150, 200, 250, 300],
    'learning_rate': [0.1, 0.5, 1.0],
    'min_samples_split': [6, 8, 10],
    'ccp_alpha': [0.0, 0.001, 0.005]
}

grid = GridSearchCV(estimator=model, param_grid=params, verbose=2)

# Fit the grid search to the data and find best hyperparameters
grid.fit(X_train, y_train.ravel())
```

```
Fitting 5 folds for each of 162 candidates, totalling 810 fits
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=6, n_estimators=50;
total time=   0.4s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=6, n_estimators=50;
total time=   0.4s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=6, n_estimators=50;
total time=   0.4s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=6, n_estimators=50;
total time=   0.4s
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total time=   0.4s
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n_estimators=100; total time=   0.9s
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n_estimators=100; total time=   0.9s
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n_estimators=100; total time=   0.9s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=6,
n_estimators=100; total time=   0.9s
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[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=6,
n_estimators=150; total time=   1.3s
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n_estimators=150; total time=   1.3s
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n_estimators=150; total time=   1.3s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=6,
n_estimators=150; total time=   1.3s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=6,
n_estimators=200; total time=   1.8s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=6,
n_estimators=200; total time=   1.8s
```

```
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=6,
n_estimators=200; total time=   1.8s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=6,
n_estimators=200; total time=   1.8s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=6,
n_estimators=200; total time=   1.8s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=6,
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n_estimators=250; total time=   2.2s
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n_estimators=250; total time=   2.2s
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n_estimators=300; total time=   2.7s
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n_estimators=300; total time=   2.7s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=6,
n_estimators=300; total time=   2.7s
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total time=   0.4s
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total time=   0.4s
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total time=   0.5s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=8, n_estimators=50;
total time=   0.5s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=8, n_estimators=50;
total time=   0.4s
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[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=8,
n_estimators=100; total time=   0.9s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=8,
n_estimators=100; total time=   0.9s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=8,
n_estimators=100; total time=   1.0s
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n_estimators=100; total time=   1.0s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=8,
n_estimators=150; total time=   1.4s
```

```
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n_estimators=150; total time=   1.4s
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n_estimators=150; total time=   1.4s
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n_estimators=200; total time=   1.8s
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n_estimators=200; total time=   1.8s
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n_estimators=200; total time=   1.9s
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n_estimators=250; total time=   2.3s
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n_estimators=250; total time=   2.4s
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n_estimators=300; total time=   2.8s
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n_estimators=50; total time=   0.5s
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n_estimators=50; total time=   0.5s
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n_estimators=50; total time=   0.5s
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n_estimators=50; total time=   0.5s
```

```
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n_estimators=100; total time=   0.9s
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n_estimators=300; total time=   2.7s
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n_estimators=300; total time=   2.7s
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=10,
n_estimators=300; total time=   2.7s
```

```
[CV] END ccp_alpha=0.0, learning_rate=0.1, min_samples_split=10,
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total time=   0.5s
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total time=   0.5s
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total time=   0.5s
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total time=   0.5s
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total time=   0.4s
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n_estimators=200; total time=   1.8s
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n_estimators=200; total time=   1.9s
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n_estimators=200; total time=   1.8s
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n_estimators=250; total time=   2.3s
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n_estimators=250; total time=   2.3s
```

```
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n_estimators=300; total time=   2.7s
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total time=   0.5s
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total time=   0.5s
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total time=   0.5s
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total time=   0.5s
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total time=   0.5s
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n_estimators=100; total time=   0.9s
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n_estimators=100; total time=   0.9s
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n_estimators=150; total time=   1.5s
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n_estimators=150; total time=   1.4s
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n_estimators=150; total time=   1.4s
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n_estimators=200; total time=   1.8s
[CV] END ccp_alpha=0.0, learning_rate=0.5, min_samples_split=8,
n_estimators=200; total time=   1.8s
```

```
[CV] END ccp_alpha=0.0, learning_rate=0.5, min_samples_split=8,
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n_estimators=100; total time=   1.0s
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n_estimators=100; total time=   0.9s
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```

```
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n_estimators=300; total time=   2.7s
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total time=   0.5s
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total time=   0.4s
```

```
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n_estimators=100; total time=   0.9s
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n_estimators=100; total time=   0.9s
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n_estimators=150; total time=   1.3s
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n_estimators=200; total time=   1.8s
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[CV] END ccp_alpha=0.0, learning_rate=1.0, min_samples_split=6,
n_estimators=250; total time=   2.2s
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n_estimators=300; total time=   2.6s
[CV] END ccp_alpha=0.0, learning_rate=1.0, min_samples_split=6,
n_estimators=300; total time=   2.7s
[CV] END ccp_alpha=0.0, learning_rate=1.0, min_samples_split=6,
n_estimators=300; total time=   2.8s
[CV] END ccp_alpha=0.0, learning_rate=1.0, min_samples_split=6,
n_estimators=300; total time=   2.8s
```

```
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n_estimators=300; total time=   2.7s
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total time=   0.4s
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total time=   0.4s
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total time=   0.4s
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total time=   0.4s
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total time=   0.5s
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n_estimators=100; total time=   0.9s
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n_estimators=100; total time=   1.0s
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n_estimators=100; total time=   1.1s
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n_estimators=100; total time=   0.9s
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n_estimators=150; total time=   1.5s
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n_estimators=200; total time=   1.8s
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n_estimators=250; total time=   2.2s
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n_estimators=250; total time=   2.3s
```

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n_estimators=250; total time=    2.3s
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n_estimators=300; total time=    2.7s
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n_estimators=300; total time=    2.7s
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n_estimators=100; total time=    0.9s
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n_estimators=100; total time=    0.9s
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n_estimators=100; total time=    0.9s
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n_estimators=150; total time=    1.4s
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n_estimators=150; total time=    1.4s
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n_estimators=150; total time=    1.4s
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n_estimators=150; total time=    1.5s
[CV] END ccp_alpha=0.0, learning_rate=1.0, min_samples_split=10,
n_estimators=200; total time=    2.1s
[CV] END ccp_alpha=0.0, learning_rate=1.0, min_samples_split=10,
n_estimators=200; total time=    2.1s
```

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n_estimators=200; total time=   1.8s
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n_estimators=200; total time=   2.0s
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n_estimators=250; total time=   2.4s
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n_estimators=300; total time=   3.1s
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n_estimators=50; total time=   0.4s
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n_estimators=50; total time=   0.4s
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n_estimators=50; total time=   0.4s
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n_estimators=50; total time=   0.4s
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n_estimators=100; total time=   0.9s
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n_estimators=100; total time=   0.9s
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n_estimators=100; total time=   0.9s
[CV] END ccp_alpha=0.001, learning_rate=0.1, min_samples_split=6,
n_estimators=150; total time=   1.3s
```

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n_estimators=200; total time=   1.8s
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n_estimators=50; total time=   0.5s
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n_estimators=50; total time=   0.4s
```

```
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```

```
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n_estimators=150; total time=    1.3s
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n_estimators=200; total time=    1.7s
```

```
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```

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```

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```
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```

```
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```

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n_estimators=300; total time=    2.6s
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n_estimators=300; total time=    2.6s
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n_estimators=300; total time=    2.6s
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n_estimators=50; total time=    0.4s
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n_estimators=50; total time=    0.4s
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n_estimators=50; total time=    0.4s
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n_estimators=50; total time=    0.4s
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n_estimators=50; total time=    0.5s
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n_estimators=200; total time=   1.8s
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n_estimators=250; total time=   2.2s
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n_estimators=250; total time=   2.2s
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n_estimators=250; total time=   2.5s
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n_estimators=300; total time=   2.9s
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n_estimators=300; total time=   2.8s
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n_estimators=300; total time=   2.8s
```

```
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n_estimators=50; total time=   0.5s
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n_estimators=150; total time=   1.3s
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n_estimators=150; total time=   1.3s
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n_estimators=200; total time=   1.7s
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n_estimators=200; total time=   1.7s
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n_estimators=200; total time=   1.7s
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n_estimators=250; total time=   2.1s
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n_estimators=250; total time=   2.2s
```

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n_estimators=150; total time=   1.3s
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n_estimators=200; total time=   1.7s
```

```
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n_estimators=100; total time=    0.9s
[CV] END ccp_alpha=0.005, learning_rate=0.5, min_samples_split=6,
n_estimators=150; total time=    1.3s
```

```
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```

```
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```

```
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```

```
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```

```
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[CV] END ccp_alpha=0.005, learning_rate=1.0, min_samples_split=8,
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[CV] END ccp_alpha=0.005, learning_rate=1.0, min_samples_split=8,
n_estimators=150; total time=   1.3s
```

```
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```

```
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```

```
[CV] END ccp_alpha=0.005, learning_rate=1.0, min_samples_split=10,
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```

[38]:
```
GridSearchCV(estimator=GradientBoostingClassifier(),
             param_grid={'ccp_alpha': [0.0, 0.001, 0.005],
                         'learning_rate': [0.1, 0.5, 1.0],
                         'min_samples_split': [6, 8, 10],
                         'n_estimators': [50, 100, 150, 200, 250, 300]},
             verbose=2)
```

Running the Gradient boosting classifier with best hyperparameters obtained using grid search

[39]:
```python
# Best parameter after tuning
print("Best parameters: ",grid.best_params_)

# Store the best model for future use
model = grid.best_estimator_

model.fit(X_train, y_train.ravel())
y_train_pred = model.predict(X_train)
y_val_pred = model.predict(X_val)
y_test_pred = model.predict(X_test)
print(f"Training accuracy: {accuracy_score(y_train.ravel(), y_train_pred)}")
print(f"Validation accuracy: {accuracy_score(y_val.ravel(), y_val_pred)}")
print(f"Testing accuracy: {accuracy_score(y_test.ravel(), y_test_pred)}")
```

```
Best parameters:  {'ccp_alpha': 0.0, 'learning_rate': 0.5, 'min_samples_split':
10, 'n_estimators': 100}
Training accuracy: 0.7926408585665006
Validation accuracy: 0.732183908045977
Testing accuracy: 0.7228541882109617
```

[ ]: