

```

In [5]: #q1
import numpy as np
from collections import Counter

class DecisionTree:
    def fit(self, X, y):
        self.tree = self.fitter(X, y)

    def fitter(self, X, y):
        samples, features = X.shape
        labels = len(np.unique(y))
        max_split = None
        max_gain = 0
        for feature in range(features):
            for threshold in np.unique(X[:, feature]):
                left = y[X[:, feature] < threshold]
                right = y[X[:, feature] >= threshold]
                if len(left) > 0 and len(right) > 0:
                    gain = self.infogain(y, left, right)
                    if gain > max_gain:
                        max_split = (feature, threshold)
                        max_gain = gain

        if max_gain == 0:
            return Counter(y).most_common(1)[0][0]

        feature, threshold = max_split
        left = X[:, feature] < threshold
        right = ~left
        l_tree = self.fitter(X[left], y[left])
        r_tree = self.fitter(X[right], y[right])
        return (feature, threshold, l_tree, r_tree)

    def entropy(self, y):
        _, l = np.unique(y, return_counts=True)
        prob = l / len(y)
        entropy = -np.sum(prob * np.log2(prob))
        return entropy

    def infogain(self, y, left, right):
        p = len(left) / len(y)
        q = len(right) / len(y)
        gain = self.entropy(y) - (p * self.entropy(left) + q * self.entropy(right))
        return gain

    def predict(self, X):
        return [self.predictor(x, self.tree) for x in X]

    def predictor(self, x, tree):
        if isinstance(tree, int) or isinstance(tree, float) or isinstance(tree, str):
            return tree
        feature = tree[0]
        threshold = tree[1]
        left = tree[2]
        right = tree[3]
        if x[feature] < threshold:
            return self.predictor(x, left)
        else:
            return self.predictor(x, right)

xtrain = np.array([[1, 2], [2, 3], [3, 4], [4, 5]])
ytrain = np.array([0, 0, 1, 1])

```

```

tree = DecisionTree()
tree.fit(xtrain, ytrain)

X_test = np.array([[4, 3], [1, 2]])
predictions = tree.predict(X_test)
print("Array of prediction is")
print(predictions)

```

Array of prediction is  
[1, 0]

```

In [7]: #2.3
import numpy as np
from collections import Counter

data = np.loadtxt("Druns.txt")

X = data[:, :-1]
y = data[:, -1]

def entropy(y):
    _, n = np.unique(y, return_counts=True)
    prob = n / len(y)
    return -np.sum(prob * np.log2(prob + 1e-10))

H = entropy(y)

cuts = []
ig_ratios = []

for feature_i in range(X.shape[1]):
    feature_values = X[:, feature_i]
    unique_values = np.unique(feature_values)

    for threshold in unique_values:
        l = np.where(feature_values < threshold)
        r = np.where(feature_values >= threshold)
        H_left = entropy(y[l])
        H_right = entropy(y[r])

        Infogain = H - (len(l[0]) / len(y) * H_left + len(r[0]) / len(y) * H_right)

        Ig_ratio = Infogain / (entropy(feature_values) + 1e-10)

        cuts.append((feature_i, threshold))
        ig_ratios.append(Ig_ratio)

    print(f"Cut: Feature {feature_i}, Threshold {threshold}")
    print(f"Information Gain: {Infogain}")
    print(f"Information Gain Ratio: {Info_gain_ratio}")
    print("\n")

```

Cut: Feature 0, Threshold 0.0  
Information Gain: 0.0  
Information Gain Ratio: 0.05464847681701849

Cut: Feature 0, Threshold 0.1  
Information Gain: 0.04417739185414593  
Information Gain Ratio: 0.05464847681701849

Cut: Feature 1, Threshold -2.0  
Information Gain: 0.0  
Information Gain Ratio: 0.05464847681701849

Cut: Feature 1, Threshold -1.0  
Information Gain: 0.04417739185414593  
Information Gain Ratio: 0.05464847681701849

Cut: Feature 1, Threshold 0.0  
Information Gain: 0.03827452220629268  
Information Gain Ratio: 0.05464847681701849

Cut: Feature 1, Threshold 1.0  
Information Gain: 0.004886164091842837  
Information Gain Ratio: 0.05464847681701849

Cut: Feature 1, Threshold 2.0  
Information Gain: 0.0010821659130776373  
Information Gain Ratio: 0.05464847681701849

Cut: Feature 1, Threshold 3.0  
Information Gain: 0.016313165825732168  
Information Gain Ratio: 0.05464847681701849

Cut: Feature 1, Threshold 4.0  
Information Gain: 0.04945207278939401  
Information Gain Ratio: 0.05464847681701849

Cut: Feature 1, Threshold 5.0  
Information Gain: 0.10519553207004628  
Information Gain Ratio: 0.05464847681701849

Cut: Feature 1, Threshold 6.0  
Information Gain: 0.19958702318968757  
Information Gain Ratio: 0.05464847681701849

Cut: Feature 1, Threshold 7.0  
Information Gain: 0.03827452220629268  
Information Gain Ratio: 0.05464847681701849

Cut: Feature 1, Threshold 8.0  
Information Gain: 0.18905266852990077  
Information Gain Ratio: 0.05464847681701849

In [8]: #2.4

```
import numpy as np
from collections import Counter

data = np.loadtxt("D3Leaves.txt")

# Extract features and labels
X = data[:, :-1] # Features
y = data[:, -1]  # Labels

class DecisionTree:
    def fit(self, X, y):
        self.tree = self.fitter(X, y)

    def fitter(self, X, y):
        samples, features = X.shape
        labels = len(np.unique(y))
        max_split = None
        max_gain = 0
        for feature in range(features):
            for threshold in np.unique(X[:, feature]):
                left = y[X[:, feature] < threshold]
                right = y[X[:, feature] >= threshold]
                if len(left) > 0 and len(right) > 0:
                    gain = self.infogain(y, left, right)
                    if gain > max_gain:
                        max_split = (feature, threshold)
                        max_gain = gain

        if max_gain == 0:
            return Counter(y).most_common(1)[0][0]

        feature, threshold = max_split
        left = X[:, feature] < threshold
        right = ~left
        l_tree = self.fitter(X[left], y[left])
        r_tree = self.fitter(X[right], y[right])
        return (feature, threshold, l_tree, r_tree)

    def entropy(self, y):
        _, l = np.unique(y, return_counts=True)
        prob = l / len(y)
        entropy = -np.sum(prob * np.log2(prob))
        return entropy

    def infogain(self, y, left, right):
        p = len(left) / len(y)
        q = len(right) / len(y)
        gain = self.entropy(y) - (p * self.entropy(left) + q * self.entropy(right))
        return gain

    def predict(self, X):
        return [self.predictor(x, self.tree) for x in X]

    def predictor(self, x, tree):
        if isinstance(tree, int) or isinstance(tree, float) or isinstance(tree, str):
            return tree
        feature = tree[0]
        threshold = tree[1]
        left = tree[2]
```

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        right = tree[3]
        if x[feature] < threshold:
            return self.predictor(x, left)
        else:
            return self.predictor(x, right)

xtrain = X
ytrain = y

tree = DecisionTree()
tree.fit(xtrain, ytrain)

X_test = np.array([[4, 3], [1, 2]])
predictions = tree.predict(X_test)
print("Array of prediction is")
print(predictions)

#The tree will have following set of logic rules:
# If Feature 1 <= 5.5 and Feature 2 <= 2 then class 0
# If Feature 1 <= 5.5 and Feature 2 > 2 then class 1
# If Feature 1 > 5.5 then class 1

```

```

Array of prediction is
[1.0, 0.0]

```

```

In [25]: #2.5
import numpy as np
from collections import Counter

data = np.loadtxt("D1.txt")
X = data[:, :-1]
y = data[:, -1]
class DecisionTree:
    def fit(self, X, y):
        self.tree = self.fitter(X, y)

    def fitter(self, X, y):
        samples, features = X.shape
        labels = len(np.unique(y))
        max_split = None
        max_gain = 0
        for feature in range(features):
            for threshold in np.unique(X[:, feature]):
                left = y[X[:, feature] < threshold]
                right = y[X[:, feature] >= threshold]
                if len(left) > 0 and len(right) > 0:
                    gain = self.infogain(y, left, right)
                    if gain > max_gain:
                        max_split = (feature, threshold)
                        max_gain = gain

        if max_gain == 0:
            return Counter(y).most_common(1)[0][0]

        feature, threshold = max_split
        left = X[:, feature] < threshold
        right = ~left
        l_tree = self.fitter(X[left], y[left])
        r_tree = self.fitter(X[right], y[right])
        return (feature, threshold, l_tree, r_tree)

    def entropy(self, y):
        _, l = np.unique(y, return_counts=True)
        prob = l / len(y)

```

```

        entropy = -np.sum(prob * np.log2(prob))
        return entropy

    def infogain(self, y, left, right):
        p = len(left) / len(y)
        q = len(right) / len(y)
        gain = self.entropy(y) - (p * self.entropy(left) + q * self.entropy(right))
        return gain

    def predict(self, X):
        return [self.predictor(x, self.tree) for x in X]

    def predictor(self, x, tree):
        if isinstance(tree, int) or isinstance(tree, float) or isinstance(tree, str):
            return tree
        feature = tree[0]
        threshold = tree[1]
        left = tree[2]
        right = tree[3]
        if x[feature] < threshold:
            return self.predictor(x, left)
        else:
            return self.predictor(x, right)

    def print_tree(self, node, features=None, classes=None, space=""):
        if isinstance(node, int) or isinstance(node, float):
            classname = classes[node] if classes else node
            print(space + "Predict", classname)
            return
        if features is None:
            feature = f"Feature {node[0]}"
        else:
            feature = features[node[0]]
        print(space + f"[{feature} < {node[1]}]")
        print(space + "--> True:")
        self.print_tree(node[2], features, classes, space + " ")
        print(space + "--> False:")
        self.print_tree(node[3], features, classes, space + " ")

X_train = X
y_train = y

tree = DecisionTree()
tree.fit(X_train, y_train)
feature_names = ["Feature 1", "Feature 2"]
print("Tree for D!")
tree.print_tree(tree.tree, feature_names)

data = np.loadtxt("D2.txt")
X = data[:, :-1]
y = data[:, -1]

X_train = X
y_train = y
print("\n\n")
tree = DecisionTree()
tree.fit(X_train, y_train)
feature_names = ["Feature 1", "Feature 2"]
print("Tree for D2")
tree.print_tree(tree.tree, feature_names)

```

```
Tree for D1
[Feature 2 < 0.201829]
--> True:
    Predict None
--> False:
    Predict None
```

```
Tree for D2
[Feature 1 < 0.533076]
--> True:
    [Feature 2 < 0.639018]
    --> True:
        [Feature 2 < 0.534979]
        --> True:
            Predict None
        --> False:
            [Feature 1 < 0.409972]
            --> True:
                Predict None
            --> False:
                [Feature 1 < 0.426073]
                --> True:
                    [Feature 1 < 0.417579]
                    --> True:
                        Predict None
                    --> False:
                        Predict None
                --> False:
                    Predict None
            --> False:
                Predict None
    --> False:
        [Feature 1 < 0.111076]
        --> True:
            [Feature 2 < 0.964767]
            --> True:
                Predict None
            --> False:
                Predict None
        --> False:
            [Feature 2 < 0.861]
            --> True:
                [Feature 1 < 0.33046]
                --> True:
                    [Feature 2 < 0.745406]
                    --> True:
                        Predict None
                    --> False:
                        [Feature 1 < 0.254049]
                        --> True:
                            [Feature 1 < 0.191915]
                            --> True:
                                Predict None
                            --> False:
                                [Feature 2 < 0.792752]
                                --> True:
                                    Predict None
                                --> False:
                                    Predict None
                        --> False:
                            Predict None
                    --> False:
                        Predict None
                --> False:
                    Predict None
            --> False:
                Predict None
```





```

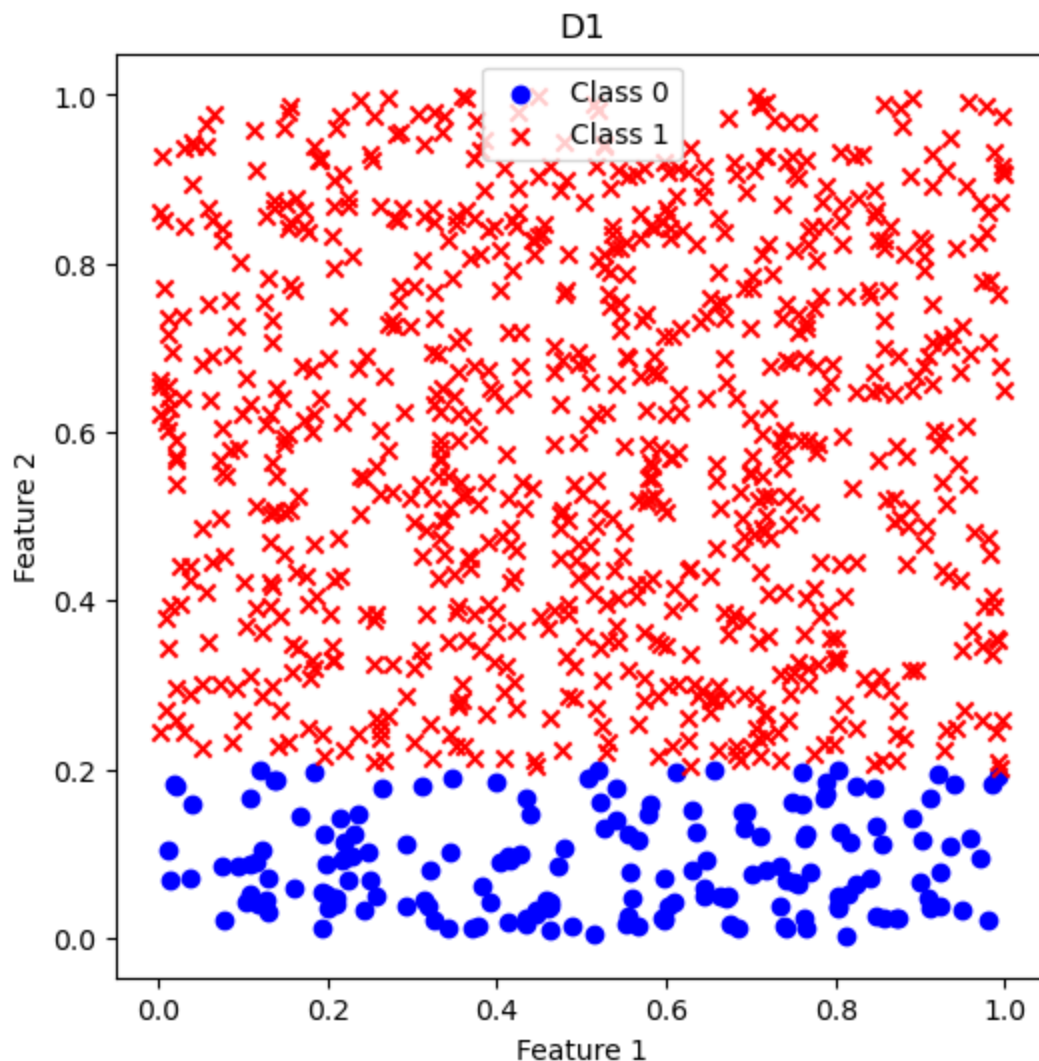
x_d2, y_d2 = d2[:, :-1], d2[:, -1]

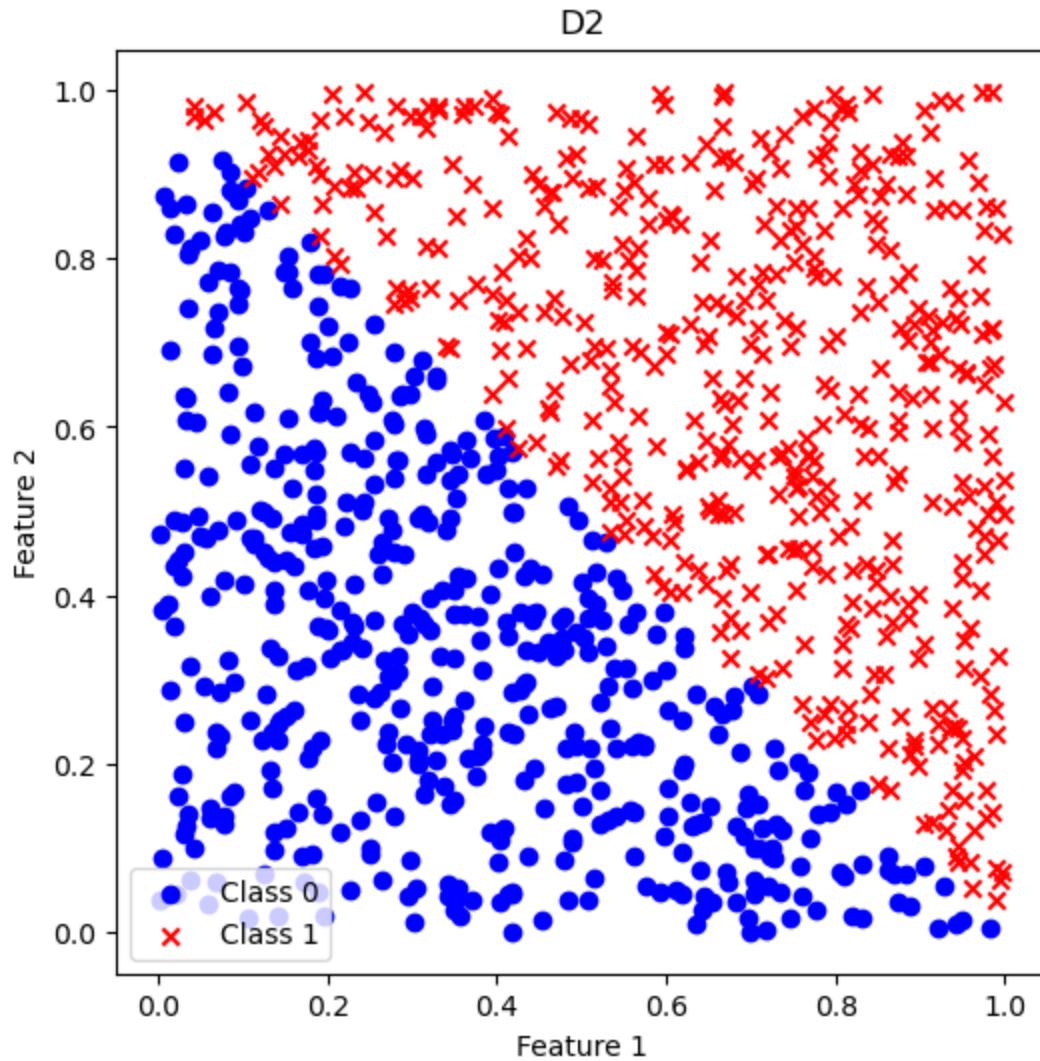
plt.figure(figsize=(6, 6))
plt.scatter(X_d1[y_d1 == 0, 0], X_d1[y_d1 == 0, 1], label="Class 0", c="blue")
plt.scatter(X_d1[y_d1 == 1, 0], X_d1[y_d1 == 1, 1], label="Class 1", c="red")
plt.title("D1")
plt.xlabel("Feature 1")
plt.ylabel("Feature 2")
plt.legend()
plt.show()

plt.figure(figsize=(6, 6))
plt.scatter(X_d2[y_d2 == 0, 0], X_d2[y_d2 == 0, 1], label="Class 0", c="blue")
plt.scatter(X_d2[y_d2 == 1, 0], X_d2[y_d2 == 1, 1], label="Class 1", c="red")
plt.title("D2")
plt.xlabel("Feature 1")
plt.ylabel("Feature 2")
plt.legend()
plt.show()

#The decision tree is complex for D2 than D1 because there is a easy split t
#straight line with slope=0, which can easily represent something above Feat
#But if we look at D2 the line has some slope, at every Feature 2 there is a
#tree to become complex.

```





In [104...

```
#2.7
import numpy as np
from collections import Counter

data = np.loadtxt("Dbig.txt")

np.random.seed(7)
np.random.shuffle(data)

train_size = 8192
train_set = data[:train_size]
test_set = data[train_size:]

class DecisionTree:
    def fit(self, X, y):
        self.tree = self.fitter(X, y)

    def fitter(self, X, y):
        samples, features = X.shape
        labels = len(np.unique(y))
        max_split = None
        max_gain = 0
        for feature in range(features):
            for threshold in np.unique(X[:, feature]):
                left = y[X[:, feature] < threshold]
                right = y[X[:, feature] >= threshold]
                if len(left) > 0 and len(right) > 0:
                    gain = self.infogain(y, left, right)
                    if gain > max_gain:
```

```

        max_split = (feature, threshold)
        max_gain = gain

    if max_gain == 0:
        return Counter(y).most_common(1)[0][0]

    feature, threshold = max_split
    left = X[:, feature] < threshold
    right = ~left
    l_tree = self.fitter(X[left], y[left])
    r_tree = self.fitter(X[right], y[right])
    return (feature, threshold, l_tree, r_tree)

def entropy(self, y):
    _, l = np.unique(y, return_counts=True)
    prob = l / len(y)
    entropy = -np.sum(prob * np.log2(prob))
    return entropy

def infogain(self, y, left, right):
    p = len(left) / len(y)
    q = len(right) / len(y)
    gain = self.entropy(y) - (p * self.entropy(left) + q * self.entropy(right))
    return gain

def predict(self, X):
    return [self.predictor(x, self.tree) for x in X]

def predictor(self, x, tree):
    if isinstance(tree, int) or isinstance(tree, float) or isinstance(tree, str):
        return tree
    feature = tree[0]
    threshold = tree[1]
    left = tree[2]
    right = tree[3]
    if x[feature] < threshold:
        return self.predictor(x, left)
    else:
        return self.predictor(x, right)

def print_tree(self, node, features=None, classes=None, space=""):
    if isinstance(node, int) or isinstance(node, float):
        classname = classes[node] if classes else node
        print(space + "Predict", classname)
        return
    if features is None:
        feature = f"Feature {node[0]}"
    else:
        feature = features[node[0]]
    print(space + f"[{feature} < {node[1]}]")
    print(space + '--> True:')
    self.print_tree(node[2], features, classes, space + " ")
    print(space + '--> False:')
    self.print_tree(node[3], features, classes, space + " ")

def node_count(self, node):
    if isinstance(node, int) or isinstance(node, float):
        return 1 # Leaf node
    else:
        feature, _, l, r = node
        left_count = self.node_count(l)
        right_count = self.node_count(r)
        return 1 + left_count + right_count

```

```

n_values = [32, 128, 512, 2048, 8192]
num_nodes = []

```

```

test_errors = []

def accuracy_score(y_true, y_pred):
    correct_predictions = 0
    total_samples = len(y_true)

    for true_label, predicted_label in zip(y_true, y_pred):
        if true_label == predicted_label:
            correct_predictions += 1

    accuracy = correct_predictions / total_samples

    return accuracy

for n in n_values:
    train_data = train_set[:n]
    X_train, y_train = train_data[:, :-1], train_data[:, -1]

    tree = DecisionTree()
    tree.fit(X_train, y_train)

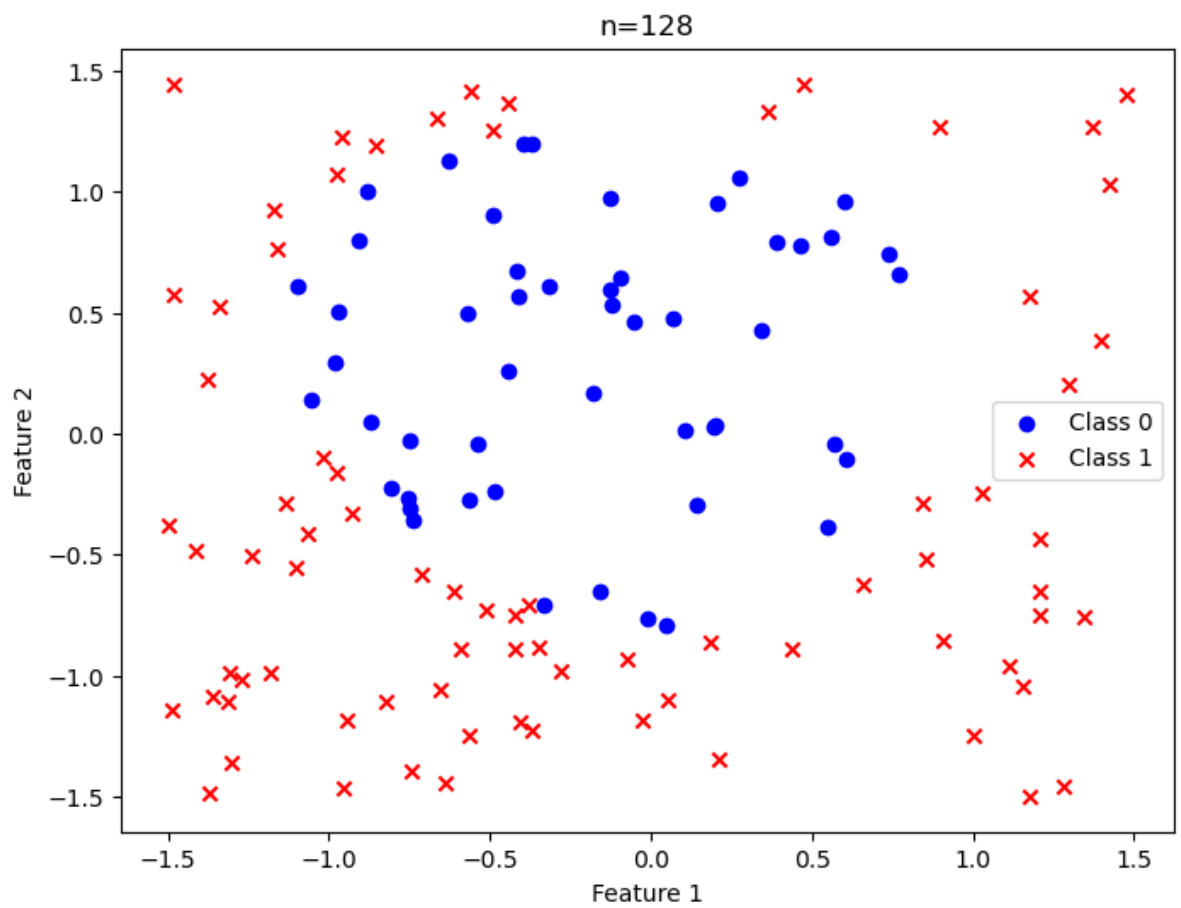
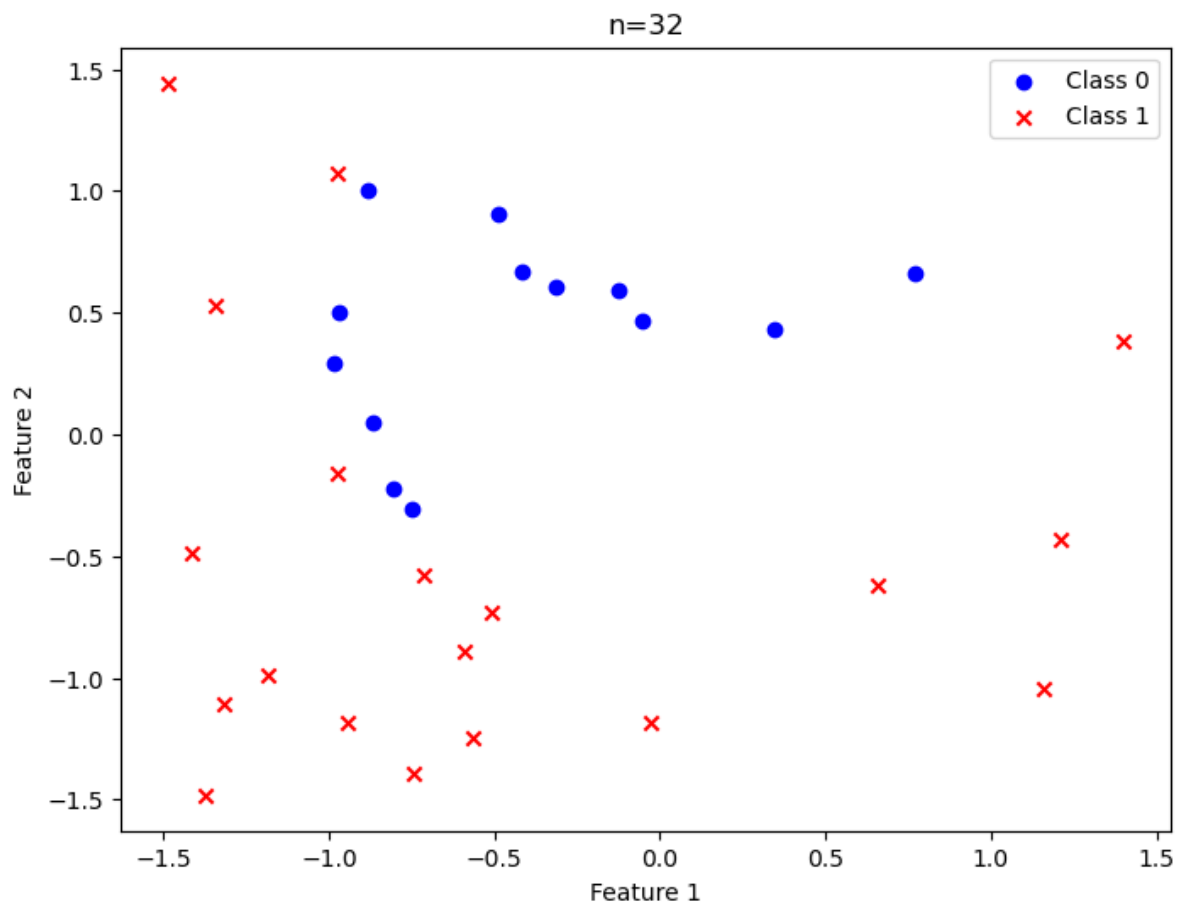
    num_nodes.append(tree.node_count(tree.tree))

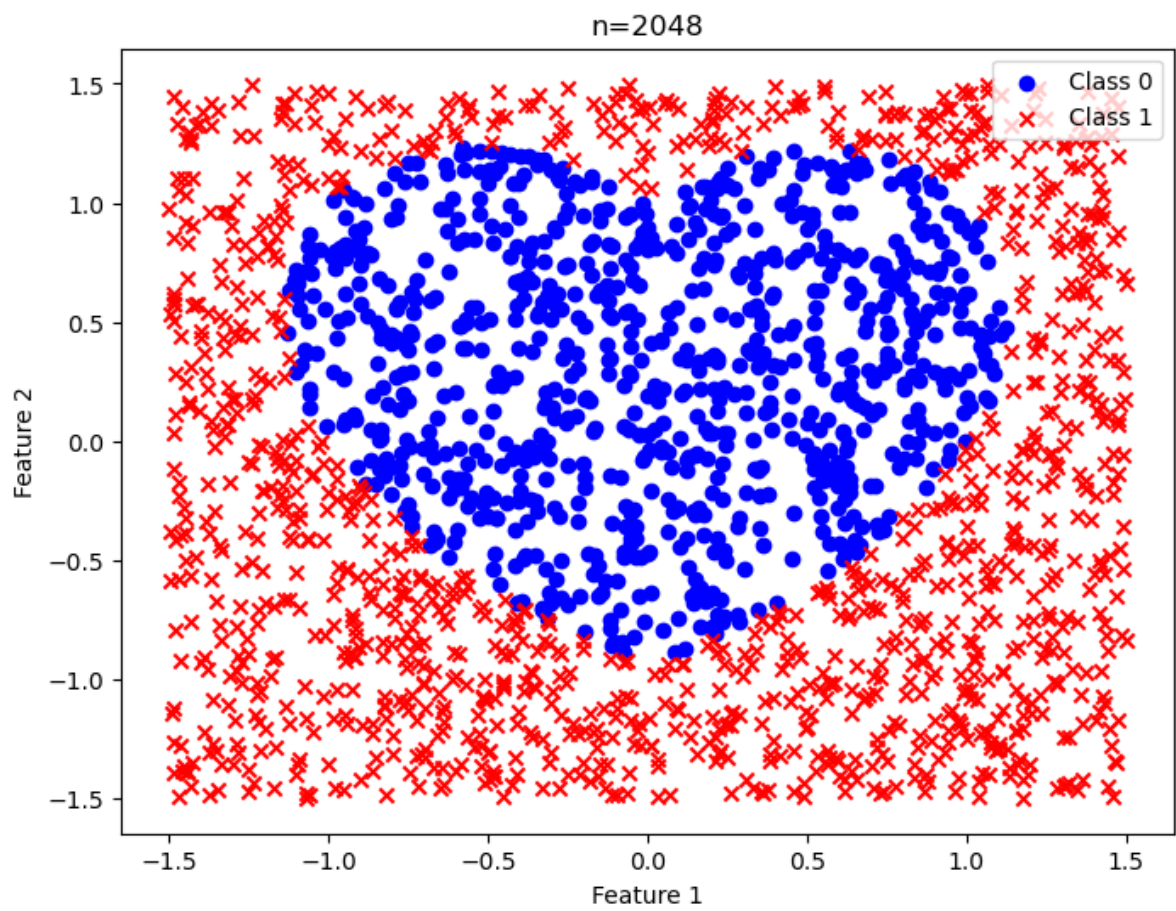
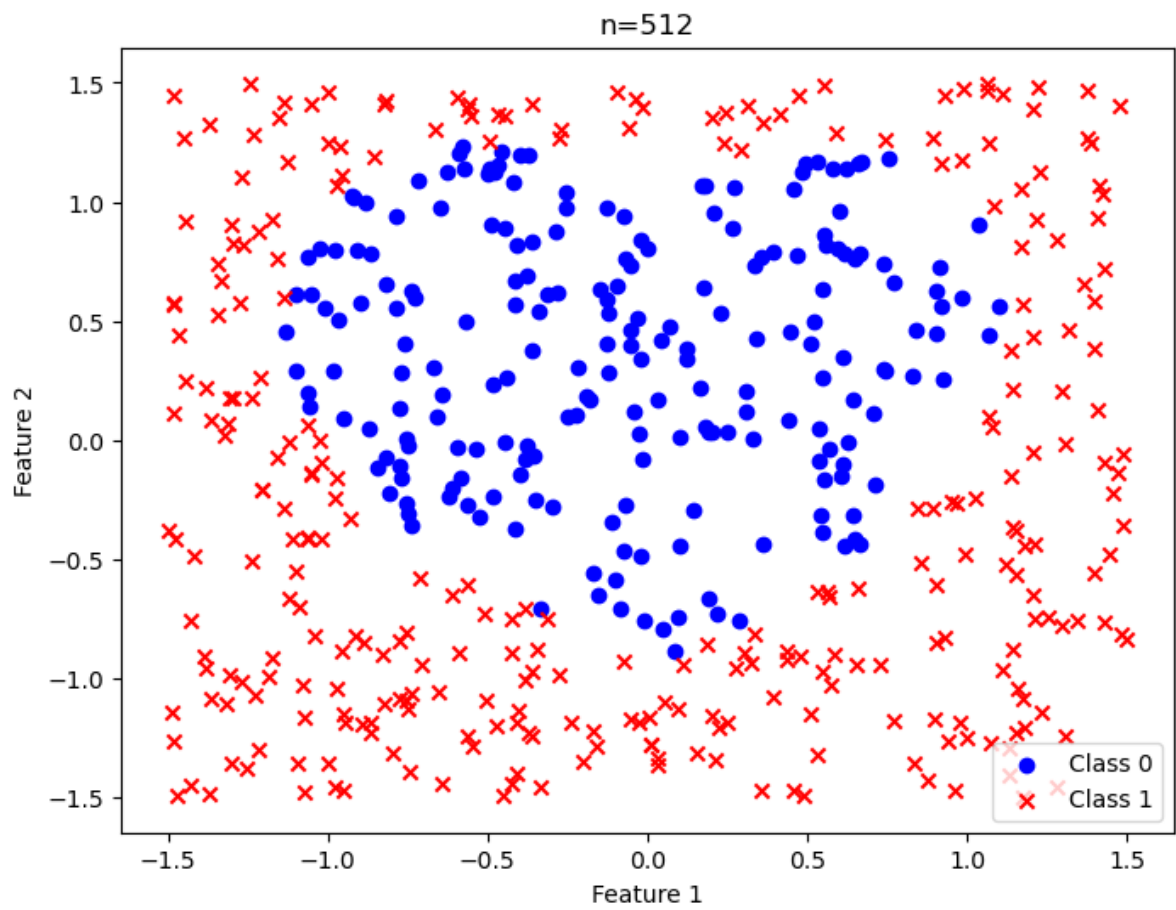
    y_pred = tree.predict(test_set[:, :-1])
    test_error = 1 - accuracy_score(test_set[:, -1], y_pred)
    test_errors.append(test_error)
    X_d1, y_d1 = train_data[:, :-1], train_data[:, -1]
    plt.figure(figsize=(8, 6))
    plt.scatter(X_d1[y_d1 == 0, 0], X_d1[y_d1 == 0, 1], label="Class 0", c="blue")
    plt.scatter(X_d1[y_d1 == 1, 0], X_d1[y_d1 == 1, 1], label="Class 1", c="red")
    plt.title("n="+str(n))
    plt.xlabel("Feature 1")
    plt.ylabel("Feature 2")
    plt.legend()
    plt.show()

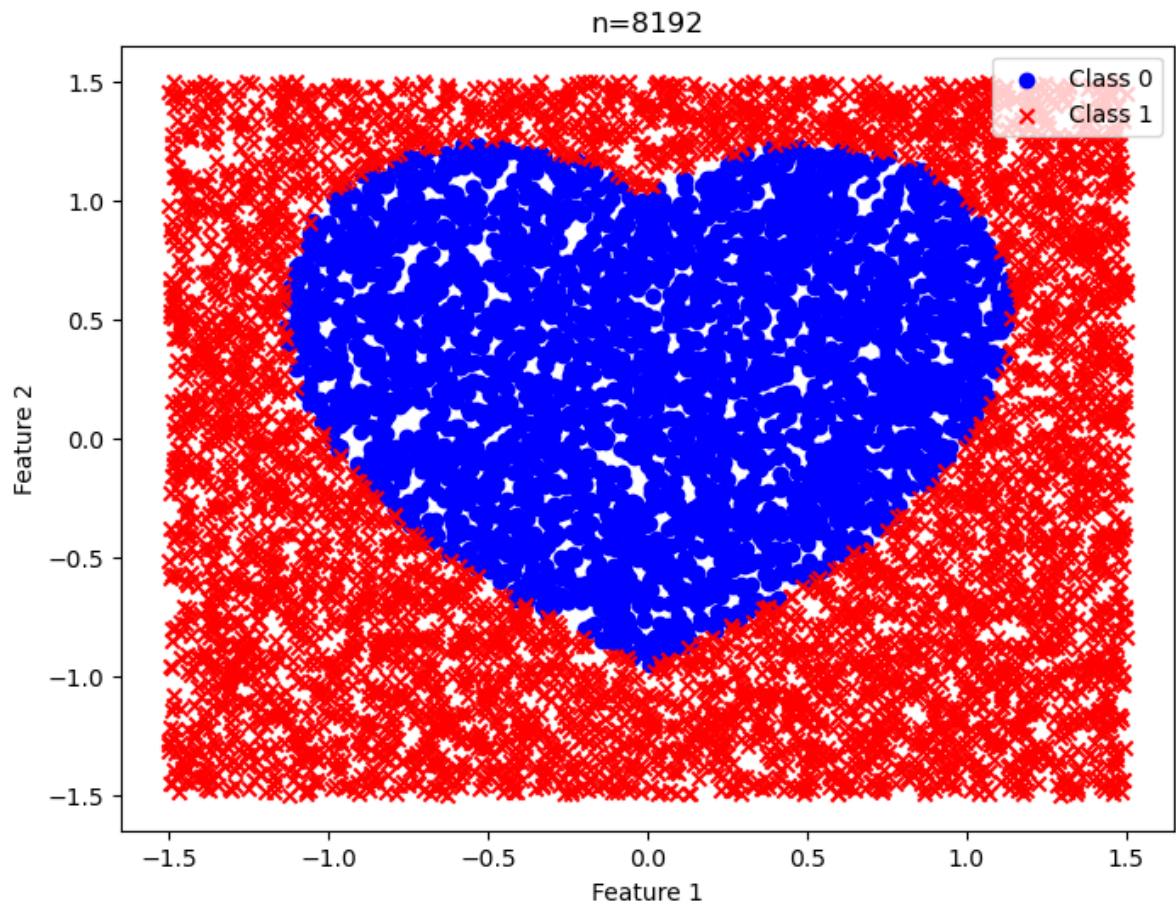
for i in range(len(n_values)):
    print(f"n = {n_values[i]}, Nodes = {num_nodes[i]}, Test Error = {test_errors[i]}")

plt.figure(figsize=(10, 5))
plt.plot(num_nodes, test_errors, marker='o')
plt.title("Learning Curve")
plt.xlabel("Nodes")
plt.ylabel("Test Error")
plt.show()

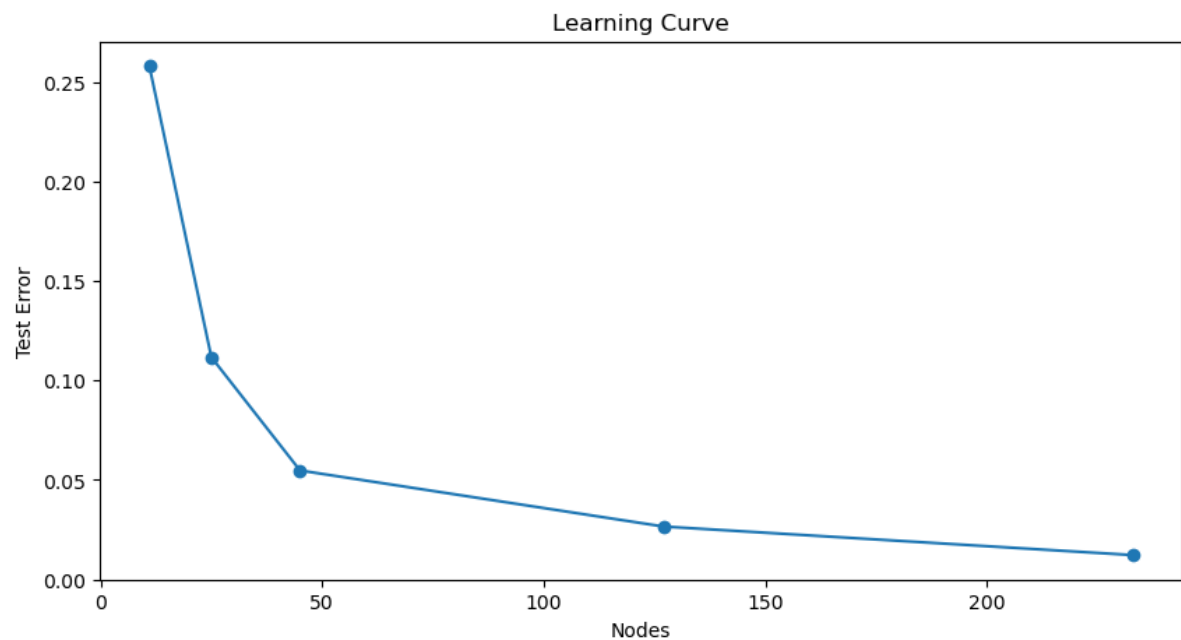
```







```
n = 32, Nodes = 11, Test Error = 0.2583
n = 128, Nodes = 25, Test Error = 0.1117
n = 512, Nodes = 45, Test Error = 0.0548
n = 2048, Nodes = 127, Test Error = 0.0265
n = 8192, Nodes = 233, Test Error = 0.0122
```



```
In [53]: #3
import numpy as np
import matplotlib.pyplot as plt
from sklearn.tree import DecisionTreeClassifier
from sklearn.metrics import accuracy_score

data = np.loadtxt("Dbig.txt")

np.random.seed(7)
```



```

np.random.shuffle(data)

n_nodes = []
t_errors = []

n_values = [32, 128, 512, 2048, 8192]

for n in n_values:
    train_data = data[:n]
    X_train, y_train = train_data[:, :-1], train_data[:, -1]

    tree = DecisionTreeClassifier(random_state=7)
    tree.fit(X_train, y_train)

    n_nodes.append(tree.tree_.node_count)

    X_test, y_test = data[n:, :-1], data[n:, -1]
    y_pred = tree.predict(X_test)
    t_error = 1 - accuracy_score(y_test, y_pred)
    t_errors.append(t_error)

print("Results:")
for i in range(len(n_values)):
    print(f"n = {n_values[i]}, Nodes = {n_nodes[i]}, Test Error = {t_errors[i]}")

plt.figure(figsize=(10, 5))
plt.plot(n_nodes, t_errors, marker='o')
plt.title("Learning Curve")
plt.xlabel("Nodes")
plt.ylabel("Test Error")
plt.show()

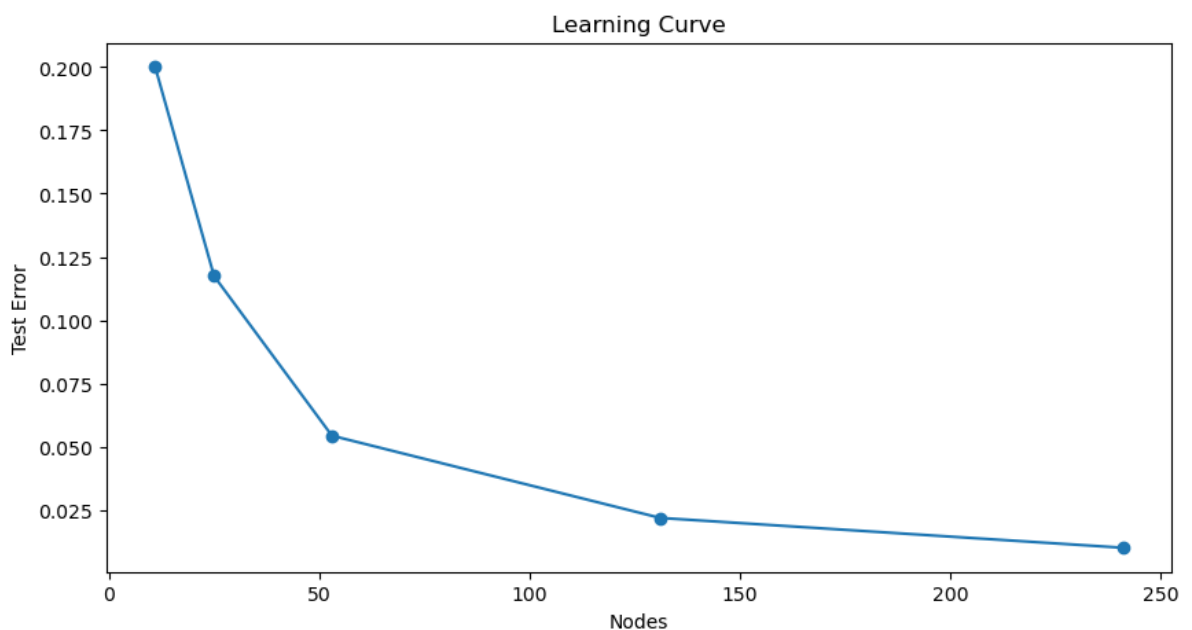
```

Results:

```

n = 32, Nodes = 11, Test Error = 0.2001
n = 128, Nodes = 25, Test Error = 0.1174
n = 512, Nodes = 53, Test Error = 0.0543
n = 2048, Nodes = 131, Test Error = 0.0218
n = 8192, Nodes = 241, Test Error = 0.0100

```



In [102...

```

#q4
#for 17 points in lagrange
import numpy as np
from scipy.interpolate import lagrange

```



```

from sklearn.metrics import mean_squared_error
from numpy.polynomial.polynomial import Polynomial

a, b, n = 0, 2*np.pi, 17

x_train = np.random.uniform(a, b, n)
y_train = np.sin(x_train)
model = lagrange(x_train, y_train)

x_test = np.random.uniform(a, b, 12)
y_test = np.sin(x_test)

y_train_pred = model(x_train)
y_test_pred = model(x_test)

train_error = mean_squared_error(y_train, y_train_pred)
test_error = mean_squared_error(y_test, y_test_pred)

print(f'Training error: {train_error}')
print(f'Testing error: {test_error}')

for std_dev in [0.1, 0.5, 1.0]:
    xn_train = x_train + np.random.normal(0, std_dev, n)
    yn_train = np.sin(xn_train)

    nlagrange = lagrange(xn_train, yn_train)

    yn_train_pred = nlagrange(xn_train)
    yn_test_pred = nlagrange(x_test)

    ntrain_error = mean_squared_error(yn_train, yn_train_pred)
    ntest_error = mean_squared_error(y_test, yn_test_pred)

    print(f"\nTrain Error (Std Dev {std_dev}): {ntrain_error:.4f}")
    print(f"Test Error (Std Dev {std_dev}): {ntest_error:.4f}")

```

Training error: 227638.22742967313

Testing error: 546286.1172889096

Train Error (Std Dev 0.1): 8.5803

Test Error (Std Dev 0.1): 26.7512

Train Error (Std Dev 0.5): 1.9755

Test Error (Std Dev 0.5): 4.0618

Train Error (Std Dev 1.0): 0.3557

Test Error (Std Dev 1.0): 0.7971

In [103]...

```

#q4
#for 100 points in lagrange
import numpy as np
from scipy.interpolate import lagrange
from sklearn.metrics import mean_squared_error
from numpy.polynomial.polynomial import Polynomial

a, b, n = 0, 2*np.pi, 100

x_train = np.random.uniform(a, b, n)
y_train = np.sin(x_train)
model = lagrange(x_train, y_train)

x_test = np.random.uniform(a, b, 12)
y_test = np.sin(x_test)

```

```

y_train_pred = model(x_train)
y_test_pred = model(x_test)

train_error = mean_squared_error(y_train, y_train_pred)
test_error = mean_squared_error(y_test, y_test_pred)

print(f'Training error: {train_error}')
print(f'Testing error: {test_error}')

for std_dev in [0.1, 0.5, 1.0]:
    xn_train = x_train + np.random.normal(0, std_dev, n)
    yn_train = np.sin(xn_train)

    nlagrange = lagrange(xn_train, yn_train)

    yn_train_pred = nlagrange(xn_train)
    yn_test_pred = nlagrange(x_test)

    ntrain_error = mean_squared_error(yn_train, yn_train_pred)
    ntest_error = mean_squared_error(y_test, yn_test_pred)

    print(f"\nTrain Error (Std Dev {std_dev}): {ntrain_error:.4f}")
    print(f"Test Error (Std Dev {std_dev}): {ntest_error:.4f}")

```

```

Training error: 4.7308517241752454e+145
Testing error: 2.558239489468512e+143

```

```

Train Error (Std Dev 0.1): 804769116641478203675236899333503430705539977386
470069735499814531246881701703674225534150242008833564280510225075447988957
83901313232621535232.0000
Test Error (Std Dev 0.1): 1417556612495417974539935803963236622522960561144
528781599125308951478932953422307136453491044706743505308114008555849564258
0310803028639744.0000

```

```

Train Error (Std Dev 0.5): 166701366862061847190678583873893790736465671187
029669387278493108264615153684180365159176889949389119800073429091147150344
51865685020770280042135552.0000
Test Error (Std Dev 0.5): 1810045157110036254649026029081493367888596433036
802550759558552194560067552361181916361360552255352093191859734719001991987
393878884096147456.0000

```

```

Train Error (Std Dev 1.0): 269458193076389965809838506495671396618891956633
499046850634638309801095654865162245462801617405986578282664192261167576460
206685476417352254100309278720.0000
Test Error (Std Dev 1.0): 3316693991057072864623418241046942748443046023105
935722435084965446414858699272620162364429710851853082027810445441365095395
270171033600.0000

```

In [ ]:

In [ ]: