CS441: Applied ML - HW 2

Part 1: Model Complexity and Tree-based Regressors

Include all the code for Part 1 in this section

```
import numpy as np
from google.colab import drive
%matplotlib inline
from matplotlib import pyplot as plt
from sklearn.linear_model import Ridge
from sklearn.linear_model import Lasso

# load data (modify to match your data directory or comment)
def load_temp_data():
    drive.mount('/content/drive')
    datadir = "/content/drive/MyDrive/"
    T = np.load(datadir + 'temperature_data.npz')
    x_train, y_train, x_val, y_val, x_test, y_test, dates_train, dates_val, dates_test, feature_to_city, feature_to_day = \
    T['x_train'], T['y_train'], T['x_val'], T['y_val'], T['x_test'], T['y_test'], T['dates_train'], T['dates_val'], T['dates_test'], T['feature_to_city'], T
    return (x_train, y_train, x_val, y_val, x_test, y_test, dates_train, dates_val, dates_test, feature_to_city, feature_to_day)

# plot one data point for listed cities and target temperature
def plot_temps(x, y, cities, feature_to_city, feature_to_day, target_date):
    nc = len(cities)
    ndays = 5
    xplot = np.array([-5,-4,-3,-2,-1])
    yplot = np.zeros((nc,ndays))
    for f in np.arange(len(x)):
        for c in np.arange(nc):
            if cities[c]==feature_to_city[f]:
                yplot[feature_to_day[f]+ndays,c] = x[f]
    plt.plot(xplot,yplot)
    plt.legend(cities)
    plt.plot(0, y, 'b*', markersize=10)
    plt.title('Predict Temp for Cleveland on ' + target_date)
    plt.xlabel('Day')
    plt.ylabel('Avg Temp (C)')
    plt.show()

# load data
(x_train, y_train, x_val, y_val, x_test, y_test, dates_train, dates_val, dates_test, feature_to_city, feature_to_day) = load_temp_data()
```

```
Drive already mounted at /content/drive; to attempt to forcibly remount, call drive.mount("/content/drive", force_remount=True).
```

```
# to plot the errors
def plot_depth_error(max_depths, tree_train_err, tree_val_err, rf_train_err, rf_val_err, bt_train_err, bt_val_err):
    plt.figure(figsize=(15,15))
    plt.semilogx(max_depths, tree_train_err, 'r.--',label='tree train')
    plt.semilogx(max_depths, tree_val_err, 'r.-', label='tree val')
    plt.semilogx(max_depths, rf_train_err, 'g.--',label='RF train')
    plt.semilogx(max_depths, rf_val_err, 'g.-', label='RF val')
    plt.semilogx(max_depths, bt_train_err, 'b.--',label='BT train')
    plt.semilogx(max_depths, bt_val_err, 'b.-', label='BT val')
    plt.ylabel('RMSE Error')
    plt.xlabel('Max Tree Depth')
    plt.xticks(max_depths, max_depths)
    plt.legend()
    plt.rcParams.update({'font.size': 20})
    plt.show()


from sklearn import tree
from sklearn.tree import DecisionTreeRegressor
from sklearn.ensemble import RandomForestRegressor
from sklearn.ensemble import GradientBoostingRegressor

max_depths = [2,4,8,16,32]
decision_error = []
decision_train_error = []
random_error = []
random_train_error = []
gradient_error = []
gradient_train_error = []
for value in max_depths:
    model = DecisionTreeRegressor(random_state=0, max_depth=value)
    model.fit(x_train, y_train)
    y_pred = model.predict(x_val)
    y_pred_train = model.predict(x_train)
    tree_error = np.sqrt(np.mean((y_val - y_pred)**2))
```

```
    tree_train_error = np.sqrt(np.mean((y_train - y_pred_train)**2))
    decision_error.append(tree_error)
    decision_train_error.append(tree_train_error)
    print("depth is ", value)
    print("the tree_error is {tree} and the tree_train error is {tree2}".format(tree = tree_error, tree2 = tree_train_error))

for value in max_depths:
    model = RandomForestRegressor(random_state=0, max_depth=value, max_features=1/3)
    model.fit(x_train, y_train)
    y_pred = model.predict(x_val)
    y_pred_train = model.predict(x_train)
    tree_error = np.sqrt(np.mean((y_val - y_pred)**2))
    tree_train_error = np.sqrt(np.mean((y_train - y_pred_train)**2))
    random_error.append(tree_error)
    random_train_error.append(tree_train_error)
    print("depth is ", value)
    print("the tree_error is {tree} and the tree_train error is {tree2}".format(tree = tree_error, tree2 = tree_train_error))

for value in max_depths:
    model = GradientBoostingRegressor(random_state=0, max_depth=value)
    model.fit(x_train, y_train)
    y_pred = model.predict(x_val)
    y_pred_train = model.predict(x_train)
    tree_error = np.sqrt(np.mean((y_val - y_pred)**2))
    tree_train_error = np.sqrt(np.mean((y_train - y_pred_train)**2))
    gradient_error.append(tree_error)
    gradient_train_error.append(tree_train_error)
    print("depth is ", value)
    print("the tree_error is {tree} and the tree_train error is {tree2}".format(tree = tree_error, tree2 = tree_train_error))
plot_depth_error(max_depths, decision_train_error, decision_error, random_train_error, random_error, gradient_train_error, gradient_error)


# usage examples
# model = DecisionTreeRegressor(random_state=0, max_depth=max_depth)
# model = RandomForestRegressor(random_state=0, max_depth=max_depth, max_features=1/3)
# model = GradientBoostingRegressor(random_state=0, max_depth=max_depth)
```

```
depth is  32
the tree_error is 3.575674665719533 and the tree_train error is 0.0
depth is  2
the tree_error is 3.2922099826318467 and the tree_train error is 3.26711283562
depth is  4
the tree_error is 2.5983948454049997 and the tree_train error is 2.50811679221
depth is  8
the tree_error is 2.463336734101179 and the tree_train error is 1.41487784315
depth is  16
the tree_error is 2.443638933567549 and the tree_train error is 0.97338710748
depth is  32
the tree_error is 2.4362441512373825 and the tree_train error is 0.97724684263
depth is  2
the tree_error is 2.521008916570206 and the tree_train error is 2.08437636979
depth is  4
the tree_error is 2.445585647819934 and the tree_train error is 1.26936586583
depth is  8
the tree_error is 2.4422287752268685 and the tree_train error is 0.03659421636
depth is  16
the tree_error is 3.28859916715485 and the tree_train error is 0.00028177600936
depth is  32
the tree_error is 3.4017131062170756 and the tree_train error is 0.00028145918
```

Part 2: MLPs with MNIST

Include all the code for Part 2 in this section

```
# initialization code
import numpy as np
from keras.datasets import mnist
%matplotlib inline
from matplotlib import pyplot as plt
from scipy import stats
import torch
import torch.nn as nn
import torch.nn.functional as F

# loads MNIST data and reformat to 768-d vectors with values in range 0 to 1
# splits into train/val/test sets and provides indices for subsets of train
def load_mnist():
    (x_train, y_train), (x_test, y_test) = mnist.load_data()
    x_train = np.reshape(x_train, (len(x_train), 28*28))
    x_test = np.reshape(x_test, (len(x_test), 28*28))
    maxval = x_train.max()
    x_train = x_train/maxval
    x_test = x_test/maxval
    x_val = x_train[:10000]
    y_val = y_train[:10000]
    x_train = x_train[10000:]
    y_train = y_train[10000:]
    train_indices = dict()
    train_indices['xs'] = np.arange(50)
    train_indices['s'] = np.arange(500)
    train_indices['m'] = np.arange(5000)
    train_indices['all'] = np.arange(50000)
    return (x_train, y_train), (x_val, y_val), (x_test, y_test), train_indices

# displays a set of mnist images
def display_mnist(x, subplot_rows=1, subplot_cols=1):
    if subplot_rows>1 or subplot_cols>1:
        fig, ax = plt.subplots(subplot_rows, subplot_cols, figsize=(15,15))
        for i in np.arange(len(x)):
            ax[i].imshow(np.reshape(x[i], (28,28)), cmap='gray')
            ax[i].axis('off')
    else:
            plt.imshow(np.reshape(x, (28,28)), cmap='gray')
            plt.axis('off')
    plt.show()

# counts the number of examples per class
def class_count_mnist(y):
    count = np.zeros((10,),dtype='uint32')
    for i in np.arange(10):
        count[i] = sum(y==i)
    return count


(x_train, y_train), (x_val, y_val), (x_test, y_test), train_indices = load_mnist()
```

```
Downloading data from https://storage.googleapis.com/tensorflow/tf-keras-datasets/mnist.npz
11490434/11490434 [==============================] - 0s 0us/step
```

```
# Sets device to "cuda" if a GPU is available (in Colabs, enable GPU by Edit->Notebook Settings-->Hardware Accelerator=GPU)
device = "cuda" if torch.cuda.is_available() else 'cpu'


def display_error_curves(num_epochs, training_losses, validation_losses):
    """
    Plots the training and validation loss curves
    """

    plt.plot(range(num_epochs), training_losses, label="Training Loss")
    plt.plot(range(num_epochs), validation_losses, label="Validation Loss")

    # Add in a title and axes labels
    plt.title('Training and Validation Loss')
    plt.xlabel('Epochs')
    plt.ylabel('Loss')

    # Display the plot
    plt.legend(loc='best')
    plt.show()


# Define the model
class MLP(nn.Module):
        def __init__(self, input_size, hidden_size, output_size):
                super(MLP, self).__init__()
                self.fc1 = nn.Linear(input_size, hidden_size)
                self.relu = nn.ReLU()
                self.fc2 = nn.Linear(hidden_size, output_size)

        def forward(self, x):
                x = self.fc1(x)
                x = self.relu(x)
                x = self.fc2(x)
                return x


def train_MLP_mnist(train_loader, val_loader, test_loader, lr=1e-2, num_epochs=100):
    input_size = 784
    # hidden_size = 64
    hidden_size = 128 # for part c
    output_size = 10
    mlp = MLP(input_size, hidden_size, output_size).to(device)
    optimizer = torch.optim.SGD(mlp.parameters(), lr=lr)
    criterion = nn.CrossEntropyLoss()
    train_loss = []
    val_loss = []
    train_error = []
    val_error = []
    test_error = []
    for epoch in range(num_epochs):
        running_train_loss = 0
        running_val_loss = 0
        train_correct = 0
        val_correct = 0
        test_correct = 0
        for x_train, y_train in train_loader:
            x_train, y_train = x_train.to(device), y_train.to(device)
            optimizer.zero_grad()
            y_pred = mlp(x_train)
            loss = criterion(y_pred, y_train)
            loss.backward()
            optimizer.step()
            running_train_loss += loss.item()
            train_correct += sum(y_train == y_pred.argmax(dim=1)).item()
        for x_val, y_val in val_loader:
            x_val, y_val = x_val.to(device), y_val.to(device)
            y_pred = mlp(x_val)
            loss = criterion(y_pred, y_val)
            running_val_loss += loss.item()
            val_correct += sum(y_val == y_pred.argmax(dim=1)).item()
        for x_test, y_test in test_loader:
            x_test, y_test = x_test.to(device), y_test.to(device)
            y_pred = mlp(x_test)
            test_correct += sum(y_test == y_pred.argmax(dim=1)).item()
        epoch_train_loss = running_train_loss / len(train_loader)
        epoch_val_loss = running_val_loss / len(val_loader)
        train_loss.append(epoch_train_loss)
        val_loss.append(epoch_val_loss)
        train_error.append(100.0 * (1 - train_correct / len(train_loader.dataset)))
        val_error.append(100.0 * (1 - val_correct / len(val_loader.dataset)))
        test_error.append(100.0 * (1 - test_correct / len(test_loader.dataset)))
        if epoch in [24, 49, 99]:
            print(f"Epoch {epoch + 1}: Train Loss = {epoch_train_loss:.4f}, Val Loss = {epoch_val_loss:.4f}")
    mlp.train_loss = train_loss
```

```
    mlp.val_loss = val_loss
    mlp.train_error = train_error
    mlp.val_error = val_error
    mlp.test_error = test_error
    return mlp



from sklearn.neural_network import MLPClassifier
from sklearn.metrics import accuracy_score
learning_rates = [1.0, 0.1, 0.01, 0.001]
num_epochs = 100
batch_size = 256
train_loader = torch.utils.data.DataLoader(torch.utils.data.TensorDataset(torch.Tensor(x_train), torch.LongTensor(y_train)), batch_size=batch_size, shuffle=True)
val_loader = torch.utils.data.DataLoader(torch.utils.data.TensorDataset(torch.Tensor(x_val), torch.LongTensor(y_val)), batch_size=batch_size, shuffle=False)
test_loader = torch.utils.data.DataLoader(torch.utils.data.TensorDataset(torch.Tensor(x_test), torch.LongTensor(y_test)), batch_size=batch_size, shuffle=False)

# for lr in learning_rates:
#         mlp = train_MLP_mnist(train_loader, val_loader, test_loader, lr, num_epochs)
#         print(f"Learning Rate: {lr}")
#         print(f"Training Loss: {mlp.train_loss[-1]:.4f}")
#         print(f"Validation Loss: {mlp.val_loss[-1]:.4f}")
#         print(f"Validation Error: {mlp.val_error[-1]:.2f}%\n")
#         display_error_curves(num_epochs, mlp.train_loss, mlp.val_loss)
# lr = 0.1
# mlp = train_MLP_mnist(train_loader, val_loader, test_loader, lr, num_epochs)
# if mlp is not None:
#     print("Train Loss: {:.4f}".format(mlp.train_loss[-1]))
#     print("Validation Loss: {:.4f}".format(mlp.val_loss[-1]))
#     print("Train Error: {:.2f}%".format(mlp.train_error[-1]))
#     print("Validation Error: {:.2f}%".format(mlp.val_error[-1]))
#     if mlp.test_error is not None:
#         print("Test Error: {:.2f}%".format(mlp.test_error[-1]))

mlp = MLPClassifier(hidden_layer_sizes=(512,512,512), activation='relu', solver='adam',
                                    alpha = 0.0001, batch_size = 256, learning_rate= 'adaptive',
                                    learning_rate_init=0.001, max_iter= 500, shuffle=True,
                                    random_state = 42, tol = 0.0001, verbose = False,
                                    early_stopping= True, validation_fraction=0.1,
                                    n_iter_no_change= 20)
mlp.fit(x_train, y_train)
y_val_pred = mlp.predict(x_val)
val_accuracy = accuracy_score(y_val, y_val_pred)
val_error = (1 - val_accuracy) * 100
print(f'Validation Error: {val_error:.4f}%')
y_test_pred = mlp.predict(x_test)
test_accuracy = accuracy_score(y_test, y_test_pred)
test_error = (1 - test_accuracy) * 100
print(f'Test Error: {test_error:.4f}%')



    Validation Error: 1.9000%
    Test Error: 1.6600%
```

Part 3: Predicting Penguin Species

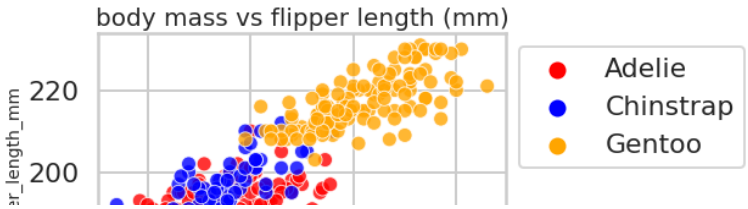
Include all your code for part 3 in this section.

```
import numpy as np
from google.colab import drive
%matplotlib inline
from matplotlib import pyplot as plt
import pandas as pd
import seaborn as sns
#styling preferences for sns
sns.set_style('whitegrid')
sns.set_context('poster')
drive.mount('/content/gdrive/')
datadir = "/content/gdrive/MyDrive/CS441/hw2/"
df_penguins = pd.read_csv(datadir + 'penguins_size.csv')
df_penguins.head(10)

def get_penguin_xy(df_penguins):
    data = np.array(df_penguins[['island', 'culmen_length_mm', 'culmen_depth_mm', 'flipper_length_mm', 'body_mass_g', 'sex']])
    y = df_penguins['species']
    ui = np.unique(data[:,0])
    us = np.unique(data[:,-1])
    X = np.zeros((len(y), 10))
    for i in range(len(y)):
        f = 0
        for j in range(len(ui)):
```

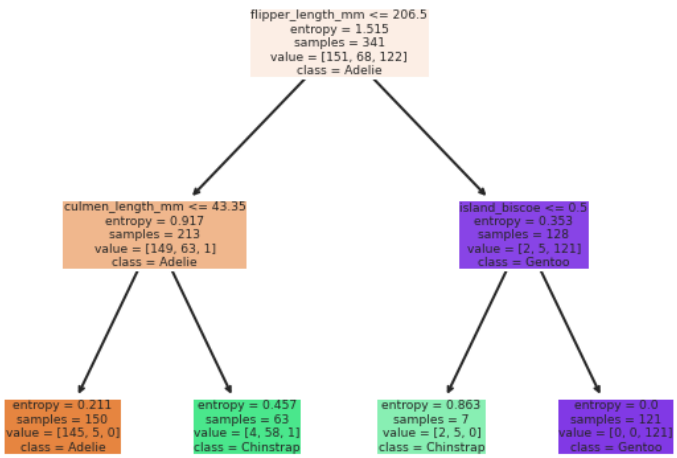
```
            if data[i, f]==ui[j]:
                X[i, f+j] = 1
        X[i, 3:7] = data[i, 1:5]
        for j in range(len(us)):
            if data[i, 5]==us[j]:
                X[i, f+j] = 1
    feature_names = ['island_biscoe', 'island_dream', 'island_torgersen', 'culmen_length_mm', 'culmen_depth_mm', 'flipper_length_mm', 'body_mass_g', 'sex_fema
    X = pd.DataFrame(X, columns=feature_names)
    return(X, y, feature_names, np.unique(y))
```

```
Drive already mounted at /content/gdrive/; to attempt to forcibly remount, call drive.mount("/content/gdrive/", force_remount=True).
```

```
palette = ["red", "blue", "orange"]

# https://seaborn.pydata.org/generated/seaborn.scatterplot.html
sns.scatterplot(data=df_penguins, x = 'body_mass_g', y = 'flipper_length_mm',
                            hue = 'species', palette=palette, alpha=0.8)

plt.xlabel('body mass', fontsize=14)
plt.ylabel('flipper_length_mm', fontsize=14)
plt.title('body mass vs flipper length (mm)', fontsize=20)
plt.legend(bbox_to_anchor=(1.0, 1.0), loc='upper left')
plt.show()

# create other visualizations
sns.scatterplot(data=df_penguins, x = 'culmen_length_mm', y = 'culmen_depth_mm',
                            hue = 'species', palette=palette, alpha=0.8)

plt.xlabel('culmen length (mm)', fontsize=14)
plt.ylabel('culmen depth (mm)', fontsize=14)
plt.title('culmen length vs culmen depth', fontsize=20)
plt.legend(bbox_to_anchor=(1.0, 1.0), loc='upper left')
plt.show()

sns.scatterplot(data=df_penguins, x = 'island', y = 'body_mass_g',
                            hue = 'species', palette=palette, alpha=0.8)

plt.xlabel('island name', fontsize=14)
plt.ylabel('body mass', fontsize=14)
plt.title('island name vs body mass', fontsize=20)
plt.legend(bbox_to_anchor=(1.0, 1.0), loc='upper left')
plt.show()
```




```
# design a classification model
from sklearn.model_selection import cross_val_score
from sklearn.tree import DecisionTreeClassifier, plot_tree
from sklearn.ensemble import RandomForestClassifier

X, y, feature_names, class_names = get_penguin_xy(df_penguins)

# model = DecisionTreeClassifier(max_depth=2, criterion='gini', random_state=0)
model = DecisionTreeClassifier(max_depth=2, criterion='entropy', random_state=0)


# Training the model on the dataset
model.fit(X, y)

# Visualizing the decision tree
plt.figure(figsize=(10,8))
plot_tree(model, feature_names=feature_names, class_names=class_names, filled=True)
plt.show()



# part3
model = RandomForestClassifier(n_estimators=150, max_depth = 8)

best_score = cross_val_score(model,np.array(X), np.array(y), cv=5)

percentage = best_score.mean() * 100
print('Best Score:{:.2f}%'.format(percentage))

# # improvement
# df_penguins['predicted_class'] = 'unknown'
# df_penguins.loc[(df_penguins['culmen_depth_mm'] <= 15) & (df_penguins['flipper_length_mm'] > 220), 'predicted_class'] = 'Gentoo'
# accuracy = sum(df_penguins['predicted_class'] == df_penguins['species']) / len(df_penguins)
# print('Accuracy of the second rule:', accuracy)
```



Part 4: Stretch Goals

Include any new code needed for Part 4 here