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ECE 472: Deep Learning
Professor Curro

Assignment 2: Binary Classification

Remarks:

Attempts to implement ReLU, Leaky-ReLU, and Sigmoid activation functions were made and unsuccessful; the functions themselves have been fully and properly implemented, however an unnecessary amount time was wasted on integrating the "handmade" activation functions into Tensorflow. The realization that "handmade" activation functions require integration was realizing that this very reason of no integration was causing my model to be unable to train due to failure of gradient computation. The quick solution that has been used instead was to utilize the built in functions instead.

MultiPerceptron Design Considerations:

One thing to note is that I don't include the input layer within my discussion of design considerations (only hidden layers and output layer).

Initially, I decided on testing 8->4->2->1 setup, however my loss didn't converge. I ramped the widths up by about 4 times, and it didn't converge. I then ramped the widths by 10 fold about and then I noticed convergence over 1500 iterations given a batch size of 32. This "funnel" design yielded losses to as low as 0.003 or possibly even lower. I tested out my final design, which is the "hourglass" configuration:

100->75->50->25->50->75->100->1

This design yielded optimal convergence compared to all permutations I have tested out thus far, yielding losses as low as 0.000002.

Citations

"Archimedean Spiral." *Wikipedia*, 20 Aug. 2021. *Wikipedia*, https://en.wikipedia.org/w/index.php?title=Archimedean_spiral&oldid=1039754847.

Brownlee, Jason. "Plot a Decision Surface for Machine Learning Algorithms in Python." *Machine Learning Mastery*, 13 Aug. 2020, https://machinelearningmastery.com/plot-a-decision-surface-for-machine-learning/.

"Python - Pandas & MatPlotLib: Plot a Bar Graph on Existing Scatter Plot or Vice Versa." *Stack Overflow*, https://stackoverflow.com/questions/49991227/pandas-matplotlib-plot-a-bar-graph-on-existing-scatter-plot-or-vice-versa Accessed 19 Sept. 2021.

```
"""
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"""

import matplotlib.pyplot as plt
import numpy as np
import tensorflow as tf
from tqdm import trange

# ---- Global Variables ----
NUM_SAMPLES = 500
BATCH_SIZE = 32
NUM_ITR = 2000
SEED = 1618
SIGMA_NOISE = 0.1
ROT_NUM = 2

# class for generating data
class Data(object):
    def __init__(self, num_samples, sigma, id, attr):

        # spiral attributes
        theta = np.random.uniform(attr["min"], attr["max"], size=(num_samples))
        spiral = self.Spiral(attr["center"], attr["gap"], theta, 1)

        # generate data
        factor = 1 if id == 1 else -1
        noise = sigma * np.random.normal(size=(num_samples))  # gaussian noise
        self.x = (
            factor * spiral.r * np.cos(theta) / 1.5 + noise
        )  # arbitrary scaling factor
        self.y = factor * spiral.r * np.sin(theta) + noise

        self.spiral = spiral._data((self.x, self.y, [id] * num_samples))

    def _init_input(self, data):
        self.data = tf.constant(data[0 : data.shape[0] - 1], dtype=np.float32)
        self.labels = tf.constant(
            data[data.shape[0] - 1], shape=[1, data.shape[1]], dtype=np.float32
        )

    def _batchGet(self, batch_size):
        self.index = NUM_SAMPLES * 2
        rand_ind = np.random.choice(self.index, size=batch_size)
        batch_data = tf.squeeze(tf.gather(self.data, rand_ind, axis=1))
        batch_labels = tf.squeeze(tf.gather(self.labels, rand_ind, axis=1))

        # normalize data
        return (
            batch_data,
            batch_labels,
        )

    # https://en.wikipedia.org/wiki/Archimedean_spiral
    class Spiral(object):
        def __init__(self, a, b, theta, n):
            self.r = a + b * (theta ** (1 / n))

        def _data(self, xy_dat):
            self.data = xy_dat
```
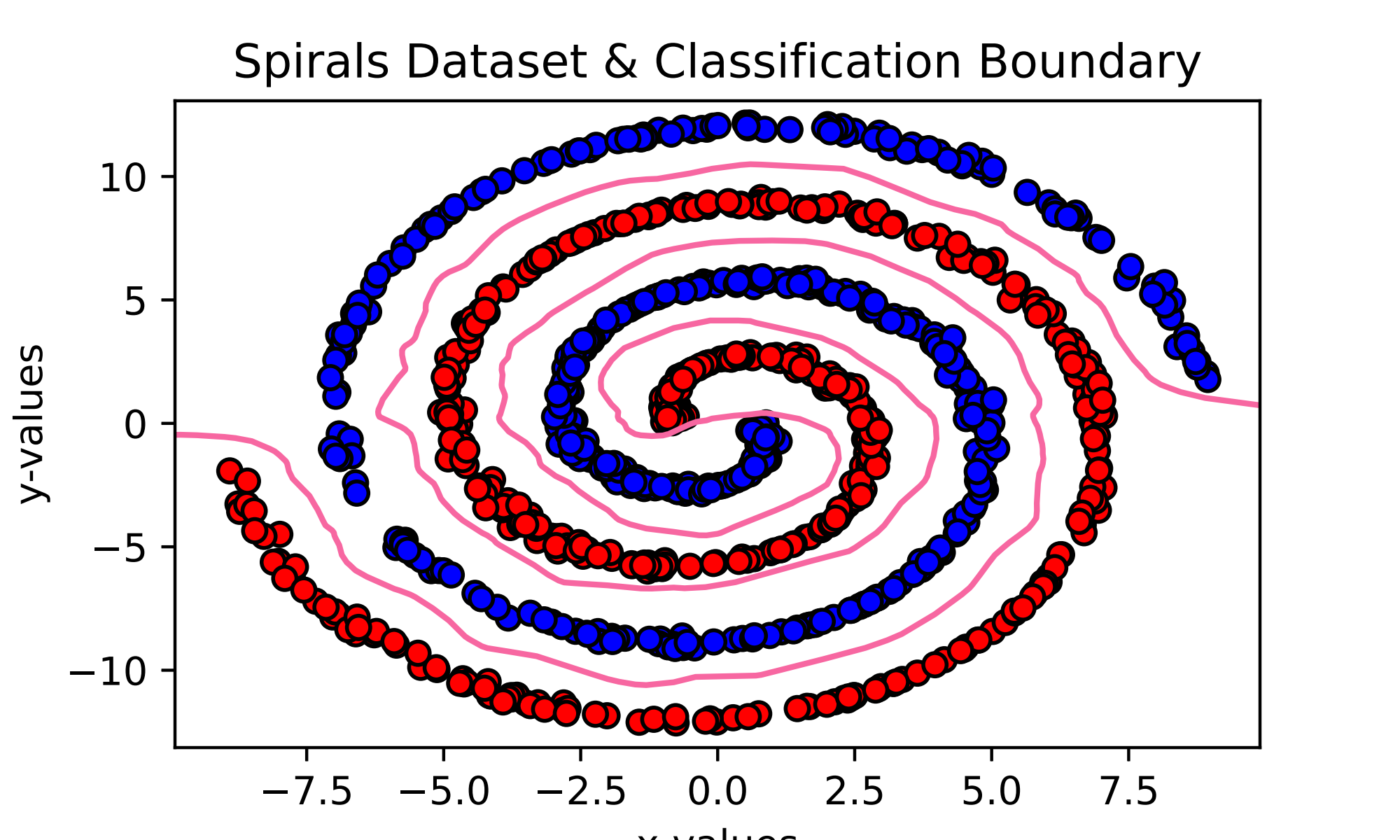



```
            return self


class MLP(tf.Module):
    def __init__(self, X_features, depth, width_arr):
        self.W = [None] * depth
        self.B = [None] * depth
        for width, k in zip(width_arr, range(1, depth + 1)):
            self.W[k - 1] = tf.Variable(
                0.2 * tf.random.normal(shape=[X_features, width]),
                name=("WEIGHTS_" + str(k)),
                dtype=np.float32,
            )
            self.B[k - 1] = tf.Variable(
                0.001 * tf.ones(shape=[width, 1]),
                name=("BIAS_" + str(k)),
                dtype=np.float32,
            )

            X_features = width

    def __call__(self, X):  # output from current layer
        X_k = X
        for W_k, B_k in zip(self.W, self.B):
            func = tf.nn.relu if W_k.shape[1] != 1 else tf.nn.sigmoid
            self.Z = tf.squeeze(func(((tf.transpose(W_k) @ X_k) + B_k)))
            X_k = tf.squeeze(self.Z)
        return self.Z  # output is the predicted probabilities for input batch


def train(data, model):
    optimizer = tf.optimizers.Adam()
    bar = trange(NUM_ITR)
    loss_dat = [0] * NUM_ITR
    for i in bar:
        with tf.GradientTape() as tape:
            X, y_true = data._batchGet(BATCH_SIZE)
            y_hat = model(X)
            loss_dat[i] = tf.losses.binary_crossentropy(y_true, y_hat)

        grads = tape.gradient(loss_dat[i], model.trainable_variables)
        optimizer.apply_gradients(zip(grads, model.trainable_variables))
        bar.set_description(f"Loss @ {i} => {loss_dat[i].numpy():0.6f}")
        bar.refresh()

    return loss_dat


# https://machinelearningmastery.com/plot-a-decision-surface-for-machine-learnin
g/
def decision_surf(data, model):
    min1, max1 = data[0, :].min() - 1, data[0, :].max() + 1
    min2, max2 = data[1, :].min() - 1, data[1, :].max() + 1

    x1grid = np.arange(min1, max1, 0.1)
    x2grid = np.arange(min2, max2, 0.1)
    X, Y = np.meshgrid(x1grid, x2grid)
    r1, r2 = X.flatten(), Y.flatten()
    r1, r2 = r1.reshape((1, len(r1))), r2.reshape((1, len(r2)))
    G = np.vstack((r1, r2))
    Z = tf.reshape(model(G), shape=X.shape)
    return (X, Y, Z)
```

```
# very messy data object setup :/
# generating 2 seperate data objects
def main():
    np.random.seed(SEED)
    # generate 2 Archimidean spirals
    dataset = (
        Data(
            NUM_SAMPLES,
            SIGMA_NOISE,
            1,
            {"min": -ROT_NUM * 2 * np.pi + 0.1, "max": -0.1, "center": -1, "gap": 1
},
        ),
        Data(
            NUM_SAMPLES,
            SIGMA_NOISE,
            0,
            {"min": -ROT_NUM * 2 * np.pi + 0.1, "max": -0.1, "center": -1, "gap": 1
},
        ),
    )

    spiral_A = list(
        zip(
            dataset[0].spiral.data[0],
            dataset[0].spiral.data[1],
            dataset[0].spiral.data[2],
        )
    )
    spiral_B = list(
        zip(
            dataset[1].spiral.data[0],
            dataset[1].spiral.data[1],
            dataset[1].spiral.data[2],
        )
    )
    input_data = np.concatenate((spiral_A, spiral_B), axis=0)
    dataset[0]._init_input(input_data.T)
    mlp_model = MLP(dataset[0].data.shape[0], 8, [100, 75, 50, 25, 50, 75, 100,
1])
    train(dataset[0], mlp_model)
    prob_surf = decision_surf(dataset[0].data.numpy(), mlp_model)

    # https://stackoverflow.com/questions/49991227/pandas-matplotlib-plot-a-bar-
graph-on-existing-scatter-plot-or-vice-versa
    fig = plt.figure(figsize=(5, 3), dpi=200)
    ax = fig.add_subplot(111)
    ax.contour(*prob_surf, cmap="RdPu", linestyles="solid", levels=1)
    ax.scatter(
        input_data[0:NUM_SAMPLES, 0],
        input_data[0:NUM_SAMPLES, 1],
        c="r",
        edgecolors="k",
    )
    ax.scatter(
        input_data[NUM_SAMPLES:, 0], input_data[NUM_SAMPLES:, 1], c="b", edgecol
ors="k"
    )
    ax.set_title("Spirals Dataset & Classification Boundary")
    ax.set(xlabel="x-values", ylabel="y-values")
```



```
    plt.savefig("output1.pdf")


if __name__ == "__main__":
    main()
```


Spirals Dataset & Classification Boundary
y-values
x-values
10
5
0
−5
−10
−7.5
−5.0
−2.5
0.0
2.5
5.0
7.5

```
compile:
	black bin_class.py
	flake8 --ignore=E,W bin_class.py
	python3 bin_class.py

pdf:
	a2ps bin_class.py -o bin_class.ps --pro=color
	a2ps Makefile -o Makefile.ps --pro=color
	ps2pdf bin_class.ps
	ps2pdf Makefile.ps
	gs -dBATCH -dNOPAUSE -q -sDEVICE=pdfwrite -sOutputFile=classif_AR.pdf RE
ADME.pdf bin_class.pdf output.pdf Makefile.pdf

clean:
	rm *.ps bin_class.pdf Makefile.pdf README.pdf
```