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Amaan Rahman
ECE 472: Deep Learning
Professor Curro

                                             Assignment 2
                                         Binary Classification

            Remarks:

                     Attempts to implement ReLU, Leaky-ReLU, and Sigmoid activat
ion functions
                     were made and unsuccessful; the functions themselves have b
een fully and
                     properly implemented, however an unecessary amount time was
 wasted on
                     integrating the "handmade" activation functions into Tensor
flow. The
                     realization that "handmade" activation functions require in
tegration
                     was realizing that this very reason of no integration was c
ausing my
                     model to be unable to train due to failure of gradient comp
utation.
                     The quick solution that has been used instead was to utiliz
e the built
                     in functions instead.

            MultiPerceptron Design Considerations:

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

                     Initially, I decided on testing 8->4->2->1 setup, however m
y loss didn't converge.
                     I ramped the widths up by about times 4, and it didn't conv
erge. 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 "hou
rglass" configruation:

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

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

                Citations:

                    Training function reference from Professor Curro's example

                    @misc{brownlee_plot_2020,
                        title = {Plot a {Decision} {Surface} for {Machine} {Lear
ning} {Algorithms} in {Python}},
                        url = {https://machinelearningmastery.com/plot-a-decisio
n-surface-for-machine-learning/},
                        abstract = {Classification algorithms learn how to assig
n class labels to examples, although their decisions can appear opaque. A popula
```



```
r diagnostic for [âM-^@¦]},
                        language = {en-US},
                        urldate = {2021-09-19},
                        journal = {Machine Learning Mastery},
                        author = {Brownlee, Jason},
                        month = aug,
                        year = {2020},
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BM7XD\\plot-a-decision-surface-for-machine-learning.html:text/html},
                    }

                    @misc{noauthor_archimedean_2021,
                        title = {Archimedean spiral},
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ense},
                        url = {https://en.wikipedia.org/w/index.php?title=Archim
edean_spiral&oldid=1039754847},
                        abstract = {The Archimedean spiral (also known as the ar
ithmetic spiral) is a spiral named after the 3rd-century BC Greek mathematician
Archimedes. It is the locus corresponding to the locations over time of a point
moving away from a fixed point with a constant speed along a line that rotates w
ith constant angular velocity. Equivalently, in polar coordinates (r, Î¸) it can
 be described by the equation




                            r
                            =
                            a
                            +
                            b
                            âM-^KM-^E
                            Î¸


                        \{{\textbackslash}displaystyle r=a+b{\textbackslash}cdot
 {\textbackslash}theta \}
                    with real numbers a and b. Changing the parameter a moves th
e centerpoint of the spiral outward from the origin (positive a toward Î¸ = 0 an
d negative a toward Î¸ = ÏM-^@) essentially through a rotation of the spiral, wh
ile b controls the distance between loops.
                    From the above equation, it can thus be stated: the position
 of particle from the point of start is proportional to the angle Î¸ as time ela
pses.
                    Archimedes described such a spiral in his book On Spirals.
Conon of Samos was a friend of his and Pappus states that this spiral was discov
ered by Conon.},
                        language = {en},
                        urldate = {2021-09-19},
                        journal = {Wikipedia},
                        month = aug,
                        year = {2021},
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LYR9E\\index.html:text/html},
                    }

                    @misc{noauthor_python_nodate,
                        title = {python - {Pandas} \& {MatPlotLib}: {Plot} a {Ba
r} {Graph} on {Existing} {Scatter} {Plot} or {Vice} {Versa}},
                        shorttitle = {python - {Pandas} \& {MatPlotLib}},
```

```
                        url = {https://stackoverflow.com/questions/49991227/pand
as-matplotlib-plot-a-bar-graph-on-existing-scatter-plot-or-vice-versa},
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                        journal = {Stack Overflow},
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37TGY\\pandas-matplotlib-plot-a-bar-graph-on-existing-scatter-plot-or-vice-versa
.html:text/html},
                    }
```

```python
"""
Amaan Rahman
ECE 472: Deep Learning
Assigment 2: Binary Classification
"""

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
```

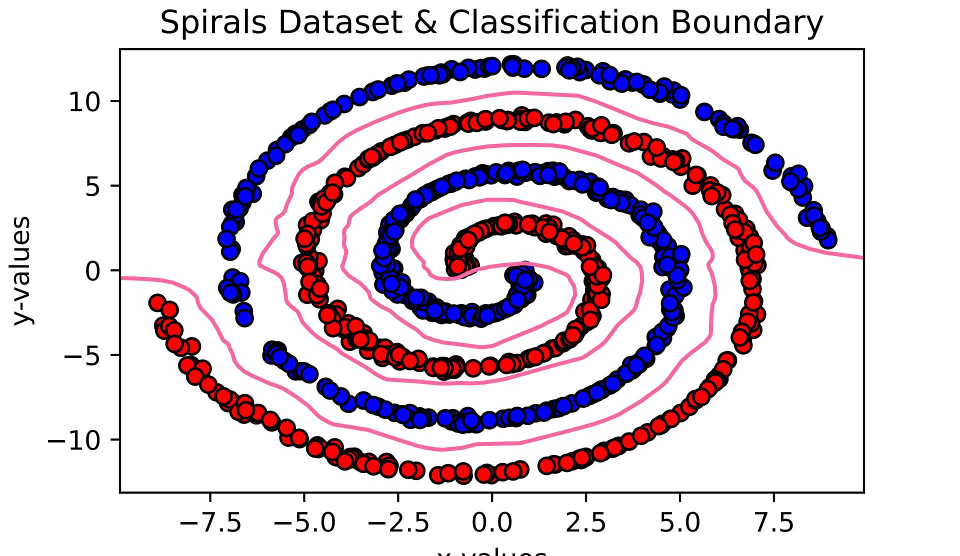


```python
            return self


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 âM-^HM-^Ro bin_class.ps âM-^HM-^RâM-^HM-^Rpro=color
	a2ps Makefile âM-^HM-^Ro Makefile.ps âM-^HM-^RâM-^HM-^Rpro=color
	a2ps README.txt âM-^HM-^Ro README.ps âM-^HM-^RâM-^HM-^Rpro=color
	ps2pdf bin_class.ps
	ps2pdf Makefile.ps
	ps2pdf README.ps
	gs âM-^HM-^RdBATCH âM-^HM-^RdNOPAUSE âM-^HM-^Rq âM-^HM-^RsDEVICE=pdfwrit
e \
		âM-^HM-^RsOutputFile=classif_AR.pdf \
		README.pdf bin_class.pdf output.pdf Makefile.pdf
```