Homework 5 (100 Points)

The focus of this homework will be Network and Graphs as well as Neural Networks.

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Exercise 1 [30pts]

This exercise will focus on Neural Networks and visualization.

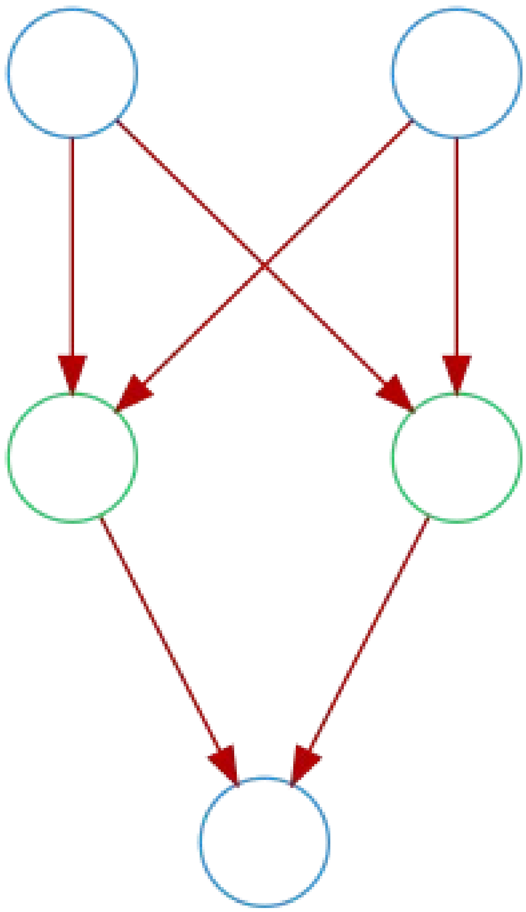
a) Write a function that takes a keras network and outputs an image (png format) of the network. [5pts]

You can assume the model is sequential and only uses dense layers. The output image for

```
model = keras.models.Sequential()
model.add(layers.Dense(2, input_dim=2))
model.add(layers.Dense(1))
model.compile(loss="binary_crossentropy")
```

should look something like this

```
from IPython.display import Image
Image(filename="example.png")
```



Hint: use the networkx library (specifically the to_agraph method)

```
!apt-get install graphviz -y
!pip install pydot
!pip install pydotplus
!apt-get install -y graphviz libgraphviz-dev pkg-config
!pip install pygraphviz
```

```
Reading package lists... Done
Building dependency tree
Reading state information... Done
graphviz is already the newest version (2.42.2-3build2).
0 upgraded, 0 newly installed, 0 to remove and 24 not upgraded.
Looking in indexes: https://pypi.org/simple, https://us-
python.pkg.dev/colab-wheels/public/simple/
Requirement already satisfied: pydot in
/usr/local/lib/python3.10/dist-packages (1.4.2)
Requirement already satisfied: pyparsing>=2.1.4 in
/usr/local/lib/python3.10/dist-packages (from pydot) (3.0.9)
Looking in indexes: https://pypi.org/simple, https://us-
python.pkg.dev/colab-wheels/public/simple/
Requirement already satisfied: pydotplus in
/usr/local/lib/python3.10/dist-packages (2.0.2)
```

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Requirement already satisfied: pyparsing>=2.0.1 in
/usr/local/lib/python3.10/dist-packages (from pydotplus) (3.0.9)
Reading package lists... Done
Building dependency tree
Reading state information... Done
pkg-config is already the newest version (0.29.1-0ubuntu4).
graphviz is already the newest version (2.42.2-3build2).
The following additional packages will be installed:
  libgail-common libgail18 libgtk2.0-0 libgtk2.0-bin libgtk2.0-common
  libgvc6-plugins-gtk libxdot4
Suggested packages:
  gvfs
The following NEW packages will be installed:
  libgail-common libgail18 libgraphviz-dev libgtk2.0-0 libgtk2.0-bin
  libgtk2.0-common libgvc6-plugins-gtk libxdot4
0 upgraded, 8 newly installed, 0 to remove and 24 not upgraded.
Need to get 2,148 kB of archives.
After this operation, 7,427 kB of additional disk space will be used.
Get:1 http://archive.ubuntu.com/ubuntu focal/main amd64 libgtk2.0-
common all 2.24.32-4ubuntu4 [126 kB]
Get:2 http://archive.ubuntu.com/ubuntu focal/main amd64 libgtk2.0-0
amd64 2.24.32-4ubuntu4 [1,791 kB]
Get:3 http://archive.ubuntu.com/ubuntu focal/main amd64 libgail18
amd64 2.24.32-4ubuntu4 [14.7 kB]
Get:4 http://archive.ubuntu.com/ubuntu focal/main amd64 libgail-common
amd64 2.24.32-4ubuntu4 [116 kB]
Get:5 http://archive.ubuntu.com/ubuntu focal/universe amd64 libxdot4
amd64 2.42.2-3build2 [15.4 kB]
Get:6 http://archive.ubuntu.com/ubuntu focal/universe amd64 libgvc6-
plugins-gtk amd64 2.42.2-3build2 [20.6 kB]
Get:7 http://archive.ubuntu.com/ubuntu focal/universe amd64
libgraphviz-dev amd64 2.42.2-3build2 [57.2 kB]
Get:8 http://archive.ubuntu.com/ubuntu focal/main amd64 libgtk2.0-bin
amd64 2.24.32-4ubuntu4 [7,728 B]
Fetched 2,148 kB in 1s (3,791 kB/s)
Selecting previously unselected package libgtk2.0-common.
(Reading database ... 122518 files and directories currently
installed.)
Preparing to unpack .../0-libgtk2.0-common_2.24.32-
4ubuntu4_all.deb ...
Unpacking libgtk2.0-common (2.24.32-4ubuntu4) ...
Selecting previously unselected package libgtk2.0-0:amd64.
Preparing to unpack .../1-libgtk2.0-0_2.24.32-4ubuntu4_amd64.deb ...
Unpacking libgtk2.0-0:amd64 (2.24.32-4ubuntu4) ...
Selecting previously unselected package libgail18:amd64.
Preparing to unpack .../2-libgail18_2.24.32-4ubuntu4_amd64.deb ...
Unpacking libgail18:amd64 (2.24.32-4ubuntu4) ...
Selecting previously unselected package libgail-common:amd64.
Preparing to unpack .../3-libgail-common_2.24.32-
4ubuntu4_amd64.deb ...
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Unpacking libgail-common:amd64 (2.24.32-4ubuntu4) ...
Selecting previously unselected package libxdot4:amd64.
Preparing to unpack .../4-libxdot4_2.42.2-3build2_amd64.deb ...
Unpacking libxdot4:amd64 (2.42.2-3build2) ...
Selecting previously unselected package libgvc6-plugins-gtk.
Preparing to unpack .../5-libgvc6-plugins-gtk_2.42.2-3build2_amd64.deb
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Unpacking libgvc6-plugins-gtk (2.42.2-3build2) ...
Selecting previously unselected package libgraphviz-dev:amd64.
Preparing to unpack .../6-libgraphviz-dev_2.42.2-3build2_amd64.deb ...
Unpacking libgraphviz-dev:amd64 (2.42.2-3build2) ...
Selecting previously unselected package libgtk2.0-bin.
Preparing to unpack .../7-libgtk2.0-bin_2.24.32-4ubuntu4_amd64.deb ...
Unpacking libgtk2.0-bin (2.24.32-4ubuntu4) ...
Setting up libxdot4:amd64 (2.42.2-3build2) ...
Setting up libgtk2.0-common (2.24.32-4ubuntu4) ...
Setting up libgtk2.0-0:amd64 (2.24.32-4ubuntu4) ...
Setting up libgvc6-plugins-gtk (2.42.2-3build2) ...
Setting up libgail18:amd64 (2.24.32-4ubuntu4) ...
Setting up libgtk2.0-bin (2.24.32-4ubuntu4) ...
Setting up libgail-common:amd64 (2.24.32-4ubuntu4) ...
Setting up libgraphviz-dev:amd64 (2.42.2-3build2) ...
Processing triggers for man-db (2.9.1-1) ...
Processing triggers for libc-bin (2.31-0ubuntu9.9) ...
Looking in indexes: https://pypi.org/simple, https://us-
python.pkg.dev/colab-wheels/public/simple/
Collecting pygraphviz
  Downloading pygraphviz-1.10.zip (120 kB)
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size=184047
sha256=cb06878bc75face7c489b1d2d7694c80c522d3cc8c055e9846817a869cc8712
8
  Stored in directory:
/root/.cache/pip/wheels/e9/50/02/d9d68f6c947a928e517d5cd9af0ab007c1274
fdba95fa9cbe3
Successfully built pygraphviz
Installing collected packages: pygraphviz
Successfully installed pygraphviz-1.10
```

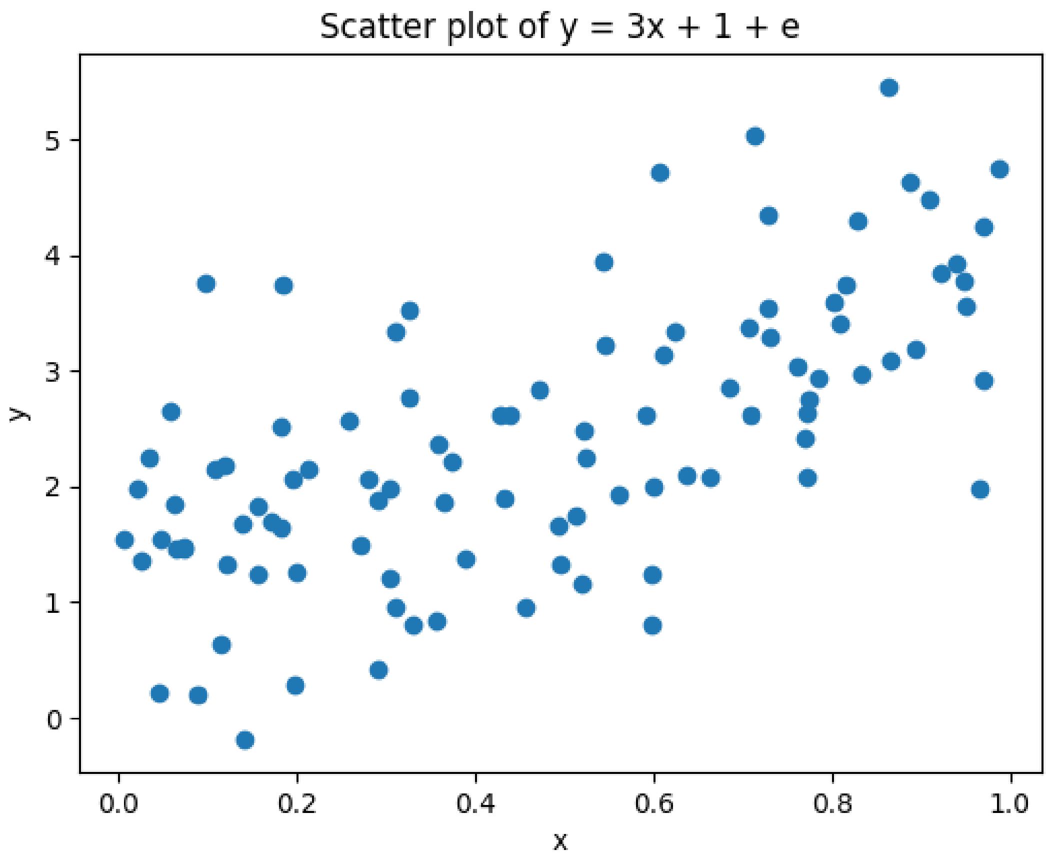
```python
import networkx as nx
from networkx.drawing.nx_agraph import to_agraph
from networkx import DiGraph, set_node_attributes
from tensorflow.keras.layers import Dense
import keras

def unique_index(layer, node):
    return str(layer) + "_" + str(node)
```

```python
def plot_keras_network(model, filename):
    graph = DiGraph(nodesep='1', ranksep='1')
    for l in range(len(model.layers)):
            layer = model.layers[l]
            for n in range(0, layer.input_shape[1]):
                if l == 0:
                    graph.add_node(
                        unique_index(l, n),
                        shape="circle",
                        color="#3498db",
                        label=''
                    )
                else:
                    graph.add_node(
                        unique_index(l, n),
                        shape="circle",
                        color="#2ecc71",
                        label=''
                    )

                for h in range(0, layer.output_shape[1]):
                    if l == len(model.layers) - 1:
                        graph.add_node(
                            unique_index(l + 1, h),
                            shape="circle",
                            color="#3498db",
                            label=''
                        )
                    graph.add_edge(
                        unique_index(l, n),
                        unique_index(l + 1, h),
                        color="#B20000"
                    )
    agraph = to_agraph(graph)
    agraph.draw(filename, prog='dot')

model = keras.models.Sequential()
model.add(keras.layers.Dense(2, input_dim=2))
model.add(keras.layers.Dense(1))
model.compile(loss="binary_crossentropy")
plot_keras_network(model, "1_a_model.png")
```

b) Generate 100 datapoints of the form $y = 3x + 1 + e$ where $e \sim N(0, 1)$ and plot the data in a scatter plot [2.5pts]

```python
import numpy as np
import matplotlib.pyplot as plt

np.random.seed(42)
x = np.random.uniform(size=100)
```

```
e = np.random.normal(loc=0, scale=1, size=100)
y = 3 * x + 1 + e

plt.scatter(x, y)
plt.title('Scatter plot of y = 3x + 1 + e')
plt.xlabel('x')
plt.ylabel('y')
plt.show()
```

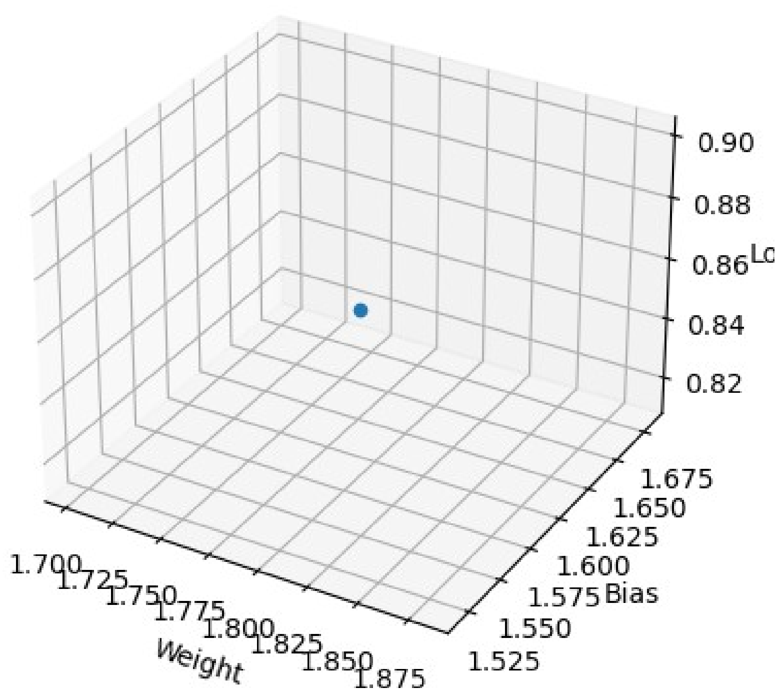


c) Create a Neural Network with no hidden layers (just input to ouput each with just one neuron), using the `mean_squared_error` loss and no activation function. Create an image of this model using a) then train this model on the dataset from b). In a 3D plot, plot the weight, the bias, and the loss value. [5pts]

```
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, Input

input_shape = (1,)

model = Sequential([
    Input(shape=input_shape),
    Dense(1, activation=None)
])
```

```
model.compile(loss='mean_squared_error',
optimizer=keras.optimizers.SGD(lr=0.01))

plot_keras_network(model, "1_c_model.png")

model.fit(x, y, epochs=100, batch_size=30, verbose=0)

weight, bias = model.layers[0].get_weights()
loss = model.evaluate(x, y)

fig = plt.figure()
ax = fig.add_subplot(111, projection='3d')
ax.scatter(weight, bias, loss)
ax.set_xlabel('Weight')
ax.set_ylabel('Bias')
ax.set_zlabel('Loss')
plt.show()
```

```
/usr/local/lib/python3.10/dist-packages/keras/optimizers/legacy/
gradient_descent.py:114: UserWarning: The `lr` argument is deprecated,
use `learning_rate` instead.
  super().__init__(name, **kwargs)

4/4 [==============================] - 0s 4ms/step - loss: 0.8568
```



d) Re-train the model from c) and create an animation of the weight, bias, and loss at each training epoch. [5pts]

```python
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense
import keras
import numpy as np
import matplotlib.pyplot as plt
from mpl_toolkits.mplot3d import Axes3D
from matplotlib.animation import FuncAnimation

input_shape = (1,)

model = Sequential([
    Input(shape=input_shape),
    Dense(1, activation=None)
])

model.compile(loss='mean_squared_error',
optimizer=keras.optimizers.SGD(lr=0.01))

def update(i):
  model.fit(x, y, epochs=1, batch_size=32)
  weight, bias = model.layers[0].get_weights()
  loss = model.evaluate(x, y)

  ax.clear()
  ax.scatter(weight, bias, loss)
  ax.set_xlabel('Weight')
  ax.set_ylabel('Bias')
  ax.set_zlabel('Loss')
  ax.set_title('Epoch {}'.format(i))

  ax.set_xlim([-3.5, 3.5])
  ax.set_ylim([-3.5, 3.5])
  ax.set_zlim([-3.5, 3.5])

fig = plt.figure()
ax = plt.axes(projection='3d')
ani = FuncAnimation(fig, update, frames=100, interval=200,
repeat=True)

ani.save('1_d_animation.gif', writer="pillow", fps=10)
```

```
/usr/local/lib/python3.10/dist-packages/keras/optimizers/legacy/
gradient_descent.py:114: UserWarning: The `lr` argument is deprecated,
use `learning_rate` instead.
  super().__init__(name, **kwargs)
```

```
4/4 [==============================] - 0s 4ms/step - loss: 6.4131
4/4 [==============================] - 0s 4ms/step - loss: 5.6974
4/4 [==============================] - 0s 3ms/step - loss: 5.4549
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4/4 [==============================] - 0s 4ms/step - loss: 0.8732
4/4 [==============================] - 0s 5ms/step - loss: 0.8723
4/4 [==============================] - 0s 5ms/step - loss: 0.8726
4/4 [==============================] - 0s 3ms/step - loss: 0.8716
4/4 [==============================] - 0s 6ms/step - loss: 0.8718
4/4 [==============================] - 0s 3ms/step - loss: 0.8710
4/4 [==============================] - 0s 4ms/step - loss: 0.8713
4/4 [==============================] - 0s 4ms/step - loss: 0.8698
4/4 [==============================] - 0s 3ms/step - loss: 0.8699
4/4 [==============================] - 0s 3ms/step - loss: 0.8683
4/4 [==============================] - 0s 4ms/step - loss: 0.8682
4/4 [==============================] - 0s 3ms/step - loss: 0.8680
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4/4 [==============================] - 0s 4ms/step - loss: 0.8673
4/4 [==============================] - 0s 7ms/step - loss: 0.8673
4/4 [==============================] - 0s 5ms/step - loss: 0.8665
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4/4 [==============================] - 0s 3ms/step - loss: 0.8656
4/4 [==============================] - 0s 3ms/step - loss: 0.8652
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4/4 [==============================] - 0s 5ms/step - loss: 0.8645
4/4 [==============================] - 0s 5ms/step - loss: 0.8652
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4/4 [==============================] - 0s 6ms/step - loss: 0.8632
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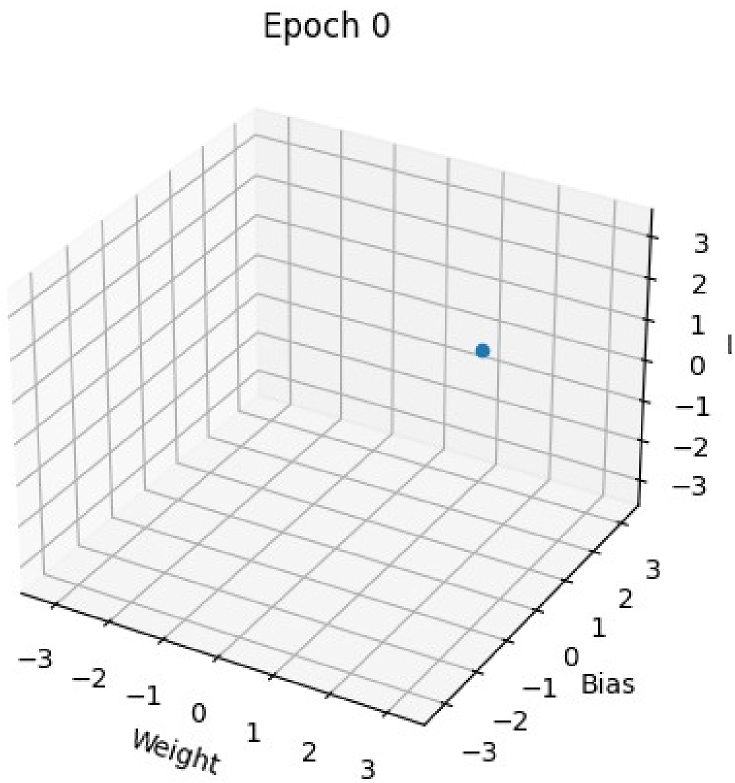
4/4 [==============================] - 0s 4ms/step - loss: 0.8629
4/4 [==============================] - 0s 4ms/step - loss: 0.8621
```

```
4/4 [==============================] - 0s 5ms/step - loss: 0.8623
4/4 [==============================] - 0s 3ms/step - loss: 0.8615
4/4 [==============================] - 0s 4ms/step - loss: 0.8615
4/4 [==============================] - 0s 4ms/step - loss: 0.8609
```

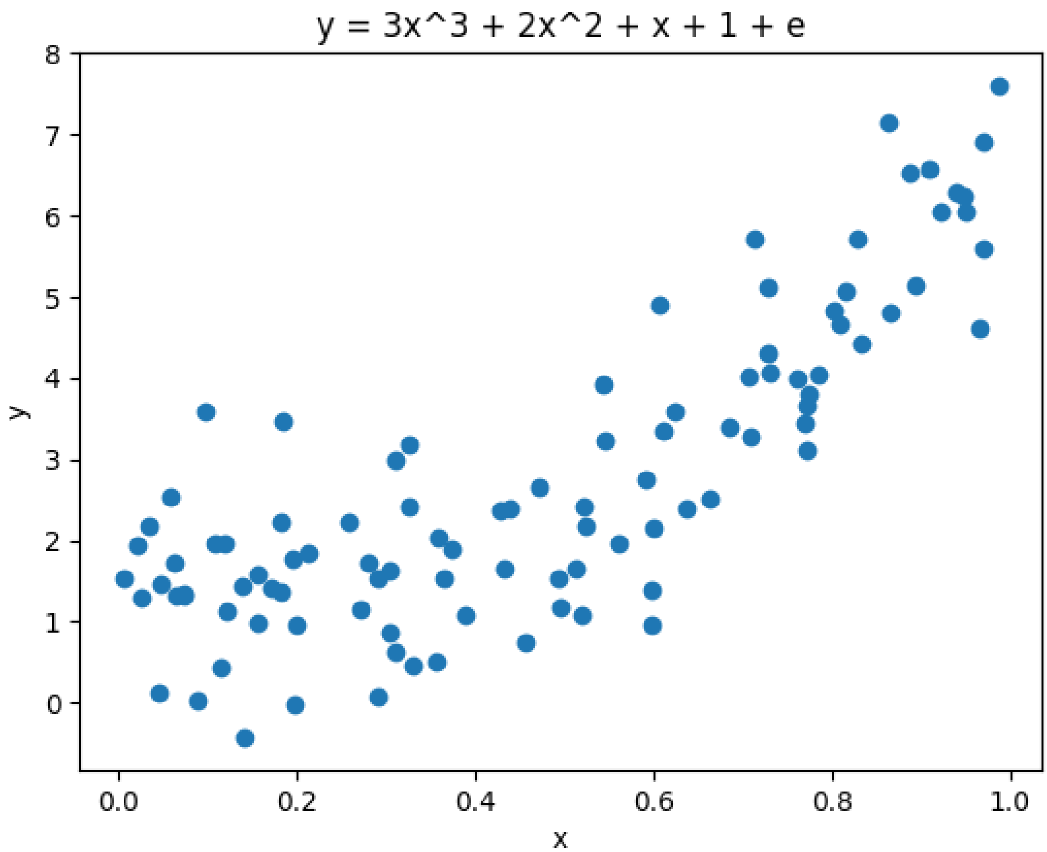


e) Generate data of the form y = 3x^3 + 2x^2 + x + 1 + e where e ~ N(0, 1) and plot the data in a scatter plot [2.5pts]

```
import numpy as np
import matplotlib.pyplot as plt

np.random.seed(42)
x = np.random.uniform(size=100)
e = np.random.normal(loc=0, scale=1, size=100)
y = 3 * x ** 3 + 2 * x ** 2 + x + 1 + e

plt.scatter(x, y)
plt.title('y = 3x^3 + 2x^2 + x + 1 + e')
plt.xlabel('x')
plt.ylabel('y')
plt.show()
```



f) Create and train a neural network on the dataset from b) and plot the resulting curve through the scatter plot. (you can use any number of epochs, hidden layers etc.) Also create an image of the network using the function from a) [5pts]

```
import numpy as np
import matplotlib.pyplot as plt
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense
from sklearn.metrics import mean_squared_error

model = Sequential()
model.add(Dense(100, input_shape=(1,), activation='relu'))
model.add(Dense(100, activation='relu'))
model.add(Dense(1))
model.compile(optimizer='adam', loss='mse')

plot_keras_network(model, '1_f_model.png')

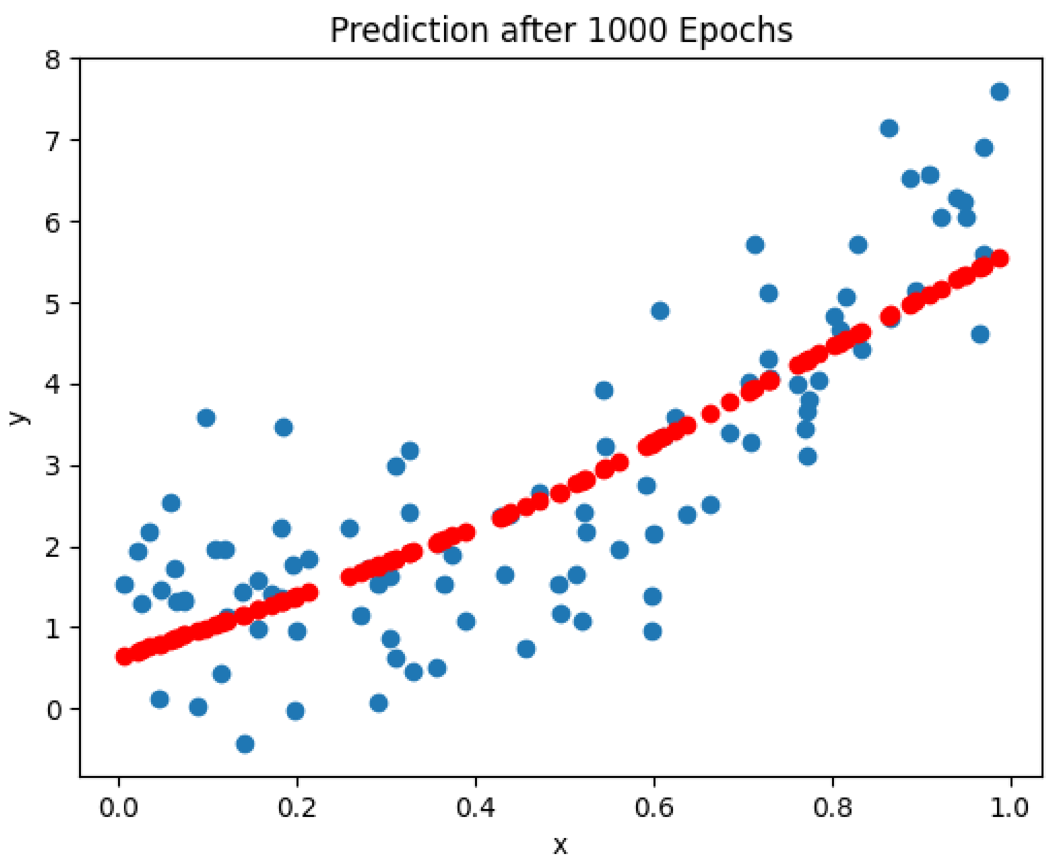
model.fit(x, y, epochs=100, verbose=0)
y_pred = model.predict(x)

mse = mean_squared_error(y, y_pred)
y_range = np.max(y) - np.min(y)
mse_norm = mse / y_range ** 2
```

```
print("Normalized MSE:", mse_norm)

plt.scatter(x, y)
plt.scatter(x, y_pred, color='red')
plt.title('Prediction after 1000 Epochs')
plt.xlabel('x')
plt.ylabel('y')
plt.show()
```

```
4/4 [==============================] - 0s 3ms/step
Normalized MSE: 0.016199355399493468
```



g) Using matplotlib animation, create an animation of the resulting curve from your model at each training epoch (up to 100 epochs). [5pts]

```
import numpy as np
import matplotlib.pyplot as plt
from matplotlib.animation import FuncAnimation
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense
from sklearn.metrics import mean_squared_error

model = Sequential()
model.add(Dense(100, input_shape=(1,), activation='relu'))
```

```
model.add(Dense(100, activation='relu'))
model.add(Dense(1))
model.compile(optimizer='adam', loss='mse')

fig, ax = plt.subplots()
ax.set_xlabel('x')
ax.set_ylabel('y')
ax.set_ylim(-110, 110)

def update(i):
    model.fit(x, y, epochs=1, verbose=0)
    y_pred = model.predict(x)
    mse = mean_squared_error(y, y_pred)
    y_range = np.max(y) - np.min(y)
    mse_norm = mse / y_range ** 2
    ax.clear()
    ax.scatter(x, y)
    ax.scatter(x, y_pred, color='red')
    ax.set_title(f'Epoch {i+1} - Normalized MSE: {mse_norm:.4f}')
    ax.set_xlabel('x')
    ax.set_ylabel('y')
    ax.set_ylim(np.min(y) - 10, np.max(y) + 10)
    fig.tight_layout()

ani = FuncAnimation(fig, update, frames=100, interval=200)
ani.save('1_g_animation.gif', writer='pillow', fps=5)
```

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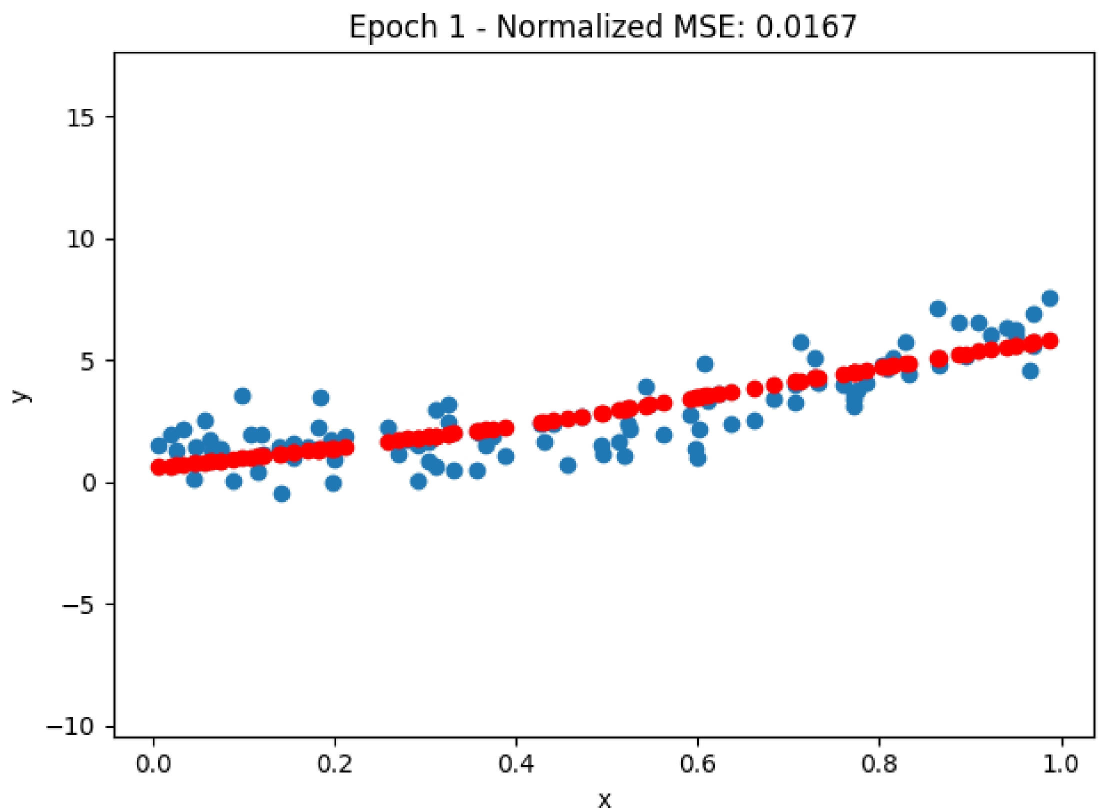
```



Exercise 2 [50pts]

In this excerise we will be implementing logic gates in various forms.

Part A: [25pts]

Recall in a logistic regression model we would find the weights and bias such that

$$P(y=1)=\sigma(w_1 x_1+w_2 x_2+b)$$

This means that when $w_1 x_1 + w_2 x_2 + b >0 $ we would predict y = 1. Moving b to the other side, we notice that only when $w_1 x_1 + w_2 x_2 < b $ do we predict y = 1. So the term b acts as a threshold past which the weighted sum of x's would cause the model to predict one class over the other.

In this part you are asked to find (not through gradient descent but through your own understanding of the functions below) the weights and threshold that appropriately describe the function being modeled.

Additional Resource/Hint: Realization of Logic Gates Using MccullochPitts Neuron Model

a) Implement the following logic gates - [20pts] 2 input AND gate 2 input OR gate 2 input NOR gate 1 input NOT gate 2 input NAND gate

by finding the correct weights and threshold.

Additional Resource:[Boolean Algebra Truth Tables for Logic Gate Functions](https://www.electronics-tutorials.ws/boolean/bool_7.html#:~:text=The%20table%20used%20to%20represent,of%20these%20input(s).)

```
"""
params
--------------
a = input 1
b = input 2

other definations
--------------
w1 = weight associated with input 1
w2 = weight associated with input 2

returns
--------------
Y = output of the gate
"""
def and_gate(a,b):
    w1 = 1  #TODO set weight w1
    w2 = 1  #TODO set weight w2
    g = w1*a + w2*b
    threshold = 1 #TODO: set threshold
    if g > threshold :
        return 1
    else:
        return 0

def or_gate(a,b):
    w1 = 1  #TODO set weight w1
    w2 = 1  #TODO set weight w2
    g = w1*a + w2*b
    threshold = 0.5 #TODO: set threshold
    if g > threshold :
        return 1
    else:
        return 0

def not_gate(a):
    w1 = -1  #TODO set weight w1
    g = w1*a
    threshold = -0.5 #TODO: set threshold
    if g > threshold :
        return 1
    else:
        return 0

def nor_gate(a,b):
    w1 = -1  #TODO set weight w1
```

```python
    w2 = -1  #TODO set weight w2
    g = w1*a + w2*b
    threshold = -1 #TODO: set threshold
    if g > threshold :
        return 1
    else:
        return 0

def nand_gate(a,b):
    w1 = -1  #TODO set weight w1
    w2 = -1  #TODO set weight w2
    g = w1*a + w2*b
    threshold = -2 #TODO: set threshold
    if g > threshold :
        return 1
    else:
        return 0

# run this cell to check your fucntions
# the output provided it just a sample output. you can check for any
values of a and b

def gates(c, a, b=None):
    if c == 1:
        return and_gate(a, b)
    elif c == 2:
        return or_gate(a, b)
    elif c == 3:
        return not_gate(a)
    elif c == 4:
        return nor_gate(a, b)
    elif c == 5:
        return nand_gate(a, b)
    else:
        return "Please check your choice"

def inputv(c):
    a = int(input(("Enter 1st value: ")))
    if (a>1 or a<0):
        print("Please check input")
    else:
        if c!=3:
            b = int(input(("Enter 2st value: ")))
            if (b>1 or b<0):
                print("Please check input")
            return(a,b)
    return(a)


while True:
```

```
    c = int(input("\n\nEnter your choice 1.AND 2.OR 3.NOT 4.NOR 5.NAND 
6.exit\n"))
    if c == 6:
        break
    elif c not in range(1, 7):
        print("Please enter a valid choice")
        continue
    else:
        if c != 3:
            a = int(input("Enter 1st value: "))
            b = int(input("Enter 2nd value: "))
            if a not in [0, 1] or b not in [0, 1]:
                print("Please check input")
                continue
        else:
            a = int(input("Enter value: "))
            if a not in [0, 1]:
                print("Please check input")
                continue
        y = gates(c, a, b)
        print("Y =", y)
```

```
Enter your choice 1.AND 2.OR 3.NOT 4.NOR 5.NAND 6.exit
5
Enter 1st value: 0
Enter 2nd value: 1
Y = 1


Enter your choice 1.AND 2.OR 3.NOT 4.NOR 5.NAND 6.exit
5
Enter 1st value: 1
Enter 2nd value: 1
Y = 0


Enter your choice 1.AND 2.OR 3.NOT 4.NOR 5.NAND 6.exit
6
```

b) implement a XOR gate - [5pts]

Hint: XOR can be implemented as a combination of OR, NAND and AND gates. You can reuse your functions from above

```
def xor_gate(a,b):
    nand = nand_gate(a,b)
    org = or_gate(a,b)
```

```python
    andg = and_gate(nand,org)
    return andg
```

Part B: Perceptron Learning Rule [25pts]

a) Inspired by the previous homework's implementation of logistic regression, implement a 2 input OR gate using perceptron learning rule - [20pts]

Recall: A perceptron is a no-hidden-layer neural network (like logistic regression) with a single output that is the activation of a weighted sum (plus a bias) of the inputs.

Your implementation should:

- use a bias
- have a configurable input size (the output size will always be 1)
- have a configurable learning rate
- have a configurable number of epochs
- have a configurable batch size
- support at least two types of activation functions
- support at least two types of losses / cost functions

```python
import numpy as np
import matplotlib.pyplot as plt

class Perceptron:
    """
    Implement a perceptron network
    """
    def __init__(self, input_size, learning_rate=0.1, epochs=100,
batch_size=1, activation='step', loss='mse'):
        self.input_size = input_size
        self.learning_rate = learning_rate
        self.epochs = epochs
        self.batch_size = batch_size
        self.activation = activation
        self.loss = loss
        self.weights = np.random.rand(self.input_size+1)

    def get_activation(self):
        activation_func=""
        if self.activation == 'step':
            activation_func = lambda x: np.where(x > 0, 1, 0)
        elif self.activation == 'sigmoid':
            activation_func = lambda x: 1 / (1 + np.exp(-x))
        else:
            raise ValueError("Invalid activation function")
        return activation_func

    def get_loss(self):
        loss_func=""
```

```
        if self.loss == 'mse':
            loss_func = lambda y_true, y_pred: np.mean((y_true -
y_pred)**2)
        elif self.loss == 'mae':
            loss_func = lambda y_true, y_pred: np.mean(np.abs(y_true -
y_pred))
        else:
            raise ValueError("Invalid loss function")
        return loss_func

    def fit(self, X, y):
        X = np.hstack([np.ones((X.shape[0],1)), X])
        activation_func = self.get_activation()
        loss_func = self.get_loss()

        loss_values = []
        for epoch in range(self.epochs):
            for i in range(0, X.shape[0], self.batch_size):
                X_batch = X[i:i+self.batch_size]
                y_batch = y[i:i+self.batch_size]
                y_pred = activation_func(np.dot(X_batch,
self.weights))
                loss = loss_func(y_batch, y_pred)
                loss_values.append(loss)
                grad = np.dot(X_batch.T, (y_pred - y_batch) * y_pred *
(1 - y_pred))
                self.weights -= self.learning_rate * grad

    def predict(self, X):
        X = np.hstack([np.ones((X.shape[0],1)), X])
        activation_func = self.get_activation()
        return np.round(activation_func(np.dot(X, self.weights)))

X = np.array([
    [0,0],
    [0,1],
    [1,0],
    [1,1]
])
y = np.array([0,1,1,1])

perceptron_or = Perceptron(input_size=2, learning_rate=0.1,
epochs=100, batch_size=1, activation='sigmoid', loss='mse')
perceptron_or.fit(X, y)

print(perceptron_or.predict(X))
```

```
[0. 1. 1. 1.]
```

b) How were the weights and biases you discovered in part B different from the ones you defined in part A for the OR gate? [5pts]

Exercise 3 [20pts]

This exercise will focus on Neural Networks.

```
from torch.utils.data import Dataset
from torchvision import datasets
from torchvision.transforms import ToTensor
import matplotlib.pyplot as plt
import torch
import torch.nn as nn
import torch.nn.functional as F
import torchvision
import torchvision.transforms as transforms
from torch.optim import SGD, Adam
from tqdm import tqdm
```

a) Modify the number of layers to include atleast 2 hidden layers with appropriate number of neurons that use the sigmoid function in the forward pass. Also change the epochs, criterion, batch_size. [5pts]

Model which gave close to 77% testing accuracy

```
class NeuralNetwork(nn.Module):
    def __init__(self, input_size):
        super(NeuralNetwork, self).__init__()
        self.layer1 = nn.Linear(input_size, 784)
        self.layer2 = nn.Linear(784, 400)
        self.layer3 = nn.Linear(400, 10)
        self.dropout = nn.Dropout(0.2)

    def forward(self, input):
        x = F.relu(self.layer1(input.view(-1, 28*28)))
        x = F.sigmoid(self.layer2(x))
        x = self.dropout(x)
        outputs = self.layer3(x)
        return F.softmax(outputs)

epochs = 10
device = torch.device("cuda" if torch.cuda.is_available() else "cpu")
criterion = nn.CrossEntropyLoss()
batch_size = 128
```

Model which improved testing performance on testing to ~89%

```
class NeuralNetwork(nn.Module):
  def __init__(self, input_size):
    super(NeuralNetwork, self).__init__()
```

```
    self.layer1 = nn.Linear(input_size, 800)
    self.layer2 = nn.Linear(800, 400)
    self.layer3 = nn.Linear(400, 10)
    self.dropout = nn.Dropout(0.2)

  def forward(self, input):
    x = F.relu(self.layer1(input))
    x = F.sigmoid(self.layer2(x))
    x = self.dropout(x)
    outputs = self.layer3(x)
    return F.softmax(outputs)

epochs = 20
device = torch.device("cuda" if torch.cuda.is_available() else "cpu")
criterion = nn.MSELoss()
batch_size = 500
```

Run the following cell everytime you update the above code

```
net = NeuralNetwork(784).to(device)
optimizer = Adam(net.parameters(), lr = 1e-2)

total_loss = 0


#######################################
### Downloading the data


training_data = datasets.FashionMNIST(
    root="data",
    train=True,
    download=True,
    transform=ToTensor()
)

test_data = datasets.FashionMNIST(
    root="data",
    train=False,
    download=True,
    transform=ToTensor()
)

train_dataloader = torch.utils.data.DataLoader(training_data,
batch_size = batch_size, shuffle = True, num_workers=2)
train_dataloader2 = torch.utils.data.DataLoader(training_data,
batch_size = batch_size, shuffle = True, num_workers=2)

test_dataloader = torch.utils.data.DataLoader(test_data, batch_size =
batch_size, shuffle = True, num_workers=2)
```

```
test_dataloader2 = torch.utils.data.DataLoader(test_data, batch_size =
batch_size, shuffle = True, num_workers=2)
```

b) You may change the architecture to increase the accuracy of this model. The goal is to attain the highest possible accuracy. You do not get marks for accuracies less than 83%. You may modify the values in part a [10pts]

```
for epoch in tqdm(range(epochs)):
  epoch_loss = 0
  for i, data in enumerate(train_dataloader):
    inputs, labels = data

    optimizer.zero_grad()
    outputs = net(inputs.view(batch_size,-1).to(device))

    labels_ = F.one_hot(labels, num_classes= 10)

    loss = criterion(outputs,labels_.to(device).float())
    loss.backward()  # update network parameters

    optimizer.step() # update the optimizer parameters

    total_loss += loss.item()
    epoch_loss += loss.item()

  with torch.no_grad():
    net.eval()
    correct = 0
    total = 0
    for i, data in enumerate(train_dataloader2):
      input, labels = data
      outputs = net(input.view(batch_size,-1).to(device))

      total+= len(labels)

      predictions = torch.argmax(outputs, dim = 1)
      predictions = predictions.to("cpu").numpy()
      correct += sum(1*(labels.numpy()==predictions))

  with torch.no_grad():
    net.eval()
    correct_test = 0
    total_test = 0
    for i, data in enumerate(test_dataloader):
      input, labels = data
      outputs = net(input.view(batch_size,-1).to(device))

      total_test+= len(labels)
```

```
      predictions = torch.argmax(outputs, dim = 1)
      predictions = predictions.to("cpu").numpy()
      correct_test += sum(1*(labels.numpy()==predictions))

  print("epoch = ", epoch, " loss = ", epoch_loss, "  training
accuracy = ", correct/total, "test accuracy = ",
correct_test/total_test)
```

```
   0%|          | 0/20 [00:00<?, ?it/s]<ipython-input-88-
01cab3ebd345>:15: UserWarning: Implicit dimension choice for softmax
has been deprecated. Change the call to include dim=X as an argument.
  return F.softmax(outputs)
  5%|▌         | 1/20 [00:34<10:50, 34.24s/it]

epoch =  0  loss =  8.6854855902493   training accuracy =
0.5314833333333333 test accuracy =  0.5242

  10%|█         | 2/20 [01:01<09:03, 30.17s/it]

epoch =  1  loss =  7.1971323899924755   training accuracy =  0.54005
test accuracy =  0.5311

  15%|█▌        | 3/20 [01:29<08:13, 29.05s/it]

epoch =  2  loss =  7.045324757695198   training accuracy =
0.5349666666666667 test accuracy =  0.5261

  20%|██        | 4/20 [01:56<07:33, 28.33s/it]

epoch =  3  loss =  6.417871594429016   training accuracy =  0.6677
test accuracy =  0.6547

  25%|██▌       | 5/20 [02:24<07:03, 28.23s/it]

epoch =  4  loss =  3.7952955327928066   training accuracy =  0.7844
test accuracy =  0.7648

  30%|███       | 6/20 [02:54<06:42, 28.77s/it]

epoch =  5  loss =  3.3493464402854443   training accuracy =  0.7909
test accuracy =  0.7713

  35%|███▌      | 7/20 [03:23<06:16, 28.98s/it]

epoch =  6  loss =  3.257948087528348   training accuracy =
0.7970666666666667 test accuracy =  0.7766

  40%|████      | 8/20 [03:53<05:50, 29.18s/it]

epoch =  7  loss =  3.0635340977460146   training accuracy =  0.89645
test accuracy =  0.8718

  45%|████▌     | 9/20 [04:25<05:29, 29.96s/it]
```

```
epoch =  8  loss =  1.9454934252426028   training accuracy =
0.8980666666666667 test accuracy =  0.8729

 50%|█████     | 10/20 [04:57<05:06, 30.61s/it]

epoch =  9  loss =  1.834816343151033   training accuracy =
0.8958166666666667 test accuracy =  0.8723

 55%|█████▌    | 11/20 [05:28<04:38, 30.89s/it]

epoch =  10  loss =  1.7833055071532726   training accuracy =
0.9088333333333334 test accuracy =  0.8802

 60%|██████    | 12/20 [06:02<04:14, 31.87s/it]

epoch =  11  loss =  1.7597284438088536   training accuracy =
0.8935166666666666 test accuracy =  0.8662

 65%|██████▌   | 13/20 [06:36<03:46, 32.29s/it]

epoch =  12  loss =  1.7457022368907928   training accuracy =
0.9004666666666666 test accuracy =  0.8736

 70%|███████   | 14/20 [07:09<03:16, 32.74s/it]

epoch =  13  loss =  1.6854582568630576   training accuracy =
0.8963333333333333 test accuracy =  0.8645

 75%|███████▌  | 15/20 [07:45<02:48, 33.66s/it]

epoch =  14  loss =  1.626717634499073   training accuracy =
0.8998166666666667 test accuracy =  0.8682

 80%|████████  | 16/20 [08:20<02:15, 33.96s/it]

epoch =  15  loss =  1.6478663124144077   training accuracy =
0.9106333333333333 test accuracy =  0.8811

 85%|████████▌ | 17/20 [08:56<01:44, 34.73s/it]

epoch =  16  loss =  1.6200494412332773   training accuracy =  0.9149
test accuracy =  0.8841

 90%|█████████ | 18/20 [09:34<01:11, 35.57s/it]

epoch =  17  loss =  1.570212583988905   training accuracy =
0.9166666666666666 test accuracy =  0.8813

 95%|█████████▌| 19/20 [10:12<00:36, 36.39s/it]

epoch =  18  loss =  1.576647930778563   training accuracy =
0.9165666666666666 test accuracy =  0.8822

100%|██████████| 20/20 [10:50<00:00, 32.53s/it]
```

```
epoch =  19  loss =  1.5130695784464478   training accuracy =
0.9212333333333333 test accuracy =  0.8872
```

d) Explain in ~150 words your choice of architecture and parameters, and your general process. [5pts]

Firstly, I tried a neural network with 10 epochs, CrossEntropy Loss and 128 (default given) batch size which gave me close to 77% testing accuracy. I changed the parameters for the model with 20 epochs, MSE loss and 500 batch size, which improved the testing accuracy to ~89%.