Question 1

- Input X
- Weights H_1 and H_2
- Bias b_1 and b_2

We compute the following:

$$H_1=\begin{bmatrix}1 & 0 & 1 & 0\\ 0 & 1 & 0 & 1\end{bmatrix}, H_2=\begin{bmatrix}1 & 1 & 0 & 1.5\end{bmatrix}$$

$$X=\begin{bmatrix}1\\ 0\end{bmatrix}$$

$$Z_1=X\,H_1+b_1$$

$$b_1=\begin{bmatrix}0.15 & 0.15 & 0.15 & 0.15\end{bmatrix}, b_2=\begin{bmatrix}0\end{bmatrix}$$

$$Z_1=\begin{bmatrix}1 & 0\end{bmatrix}\begin{bmatrix}1 & 0 & 1 & 0\\ 0 & 1 & 0 & 1\end{bmatrix}+\begin{bmatrix}0.15\\ 0.15\\ 0.15\\ 0.15\end{bmatrix}=\begin{bmatrix}1\\ 0\\ 1\\ 0\end{bmatrix}\begin{bmatrix}0.15\\ 0.15\\ 0.15\\ 0.15\end{bmatrix}=\begin{bmatrix}1.15\\ 0.15\\ 1.15\\ 0.15\end{bmatrix}$$

$ A_1 = \tanh(Z_1) $

$$A_1=\begin{bmatrix}0.81\\ 0.14\\ 0.81\\ 0.14\end{bmatrix}$$

$ Z_2 = H_2A_1 + B_2^T $

$$Z_2=\begin{bmatrix}1 & 1 & 0 & 1.5\end{bmatrix}\begin{bmatrix}0.81\\ 0.14\\ 0.81\\ 0.14\end{bmatrix}+\begin{bmatrix}0\end{bmatrix}$$

$$Z_2=\begin{bmatrix}1.187\end{bmatrix}$$

$ A_2 = \tanh(Z_2) $

$ A_2 = 0.83 (rounded-off) $

$$MSE=\left(Y_T-Y_P\right)^2$$

$$\partial MSE/\partial Y_P=-2\left(Y_T-Y_P\right)$$

$$\partial tanh(x)/\partial x=1-tanh^2(x)=1-0.83^2=0.31$$

$$\partial MSE/\partial Y_p = -2(1-0.83) = -0.34$$

$$\partial MSE/\partial H_2 = \partial MSE/\partial Y_p \cdot \partial Y_p/\partial H_2 = -0.34 \cdot \begin{bmatrix} 0.81 \\ 0.14 \\ 0.81 \\ 0.14 \end{bmatrix}$$

$$\partial H_2 new = H_2 - \partial tanh(x)/\partial x \cdot \alpha \cdot \partial MSE/\partial H_2$$

$$\partial H_2 new = \begin{bmatrix} 1 & 1 & 0 & 1.5 \end{bmatrix} - 0.3111 \cdot (-0.34 \cdot 10) \cdot \begin{bmatrix} 0.81 \\ 0.14 \\ 0.81 \\ 0.14 \end{bmatrix}$$

$$\partial H_2 new = \begin{bmatrix} 1.85 \\ 1.15 \\ 0.85 \\ 1.65 \end{bmatrix}$$

$B_2new = 0 - (-0.34)·10·0.3111 $

$B_2new = 1.05 $

Question 2

```
import numpy as np
import matplotlib.pyplot as plt
from nnet import Network, ActivationLayer, FCLayer,
mean_squared_error_loss, mse_loss_derivative, tanh, tanh_derivative,
binary_cross_entropy, binary_cross_entropy_prime, sigmoid,
sigmoid_derivative
```

Testing the FCLayer and ActivationLayer classes.

```
# Testing the modified FCLayer class
network1 = Network(loss_function=mean_squared_error_loss,
loss_derivative=mse_loss_derivative)
input_size = 2
hidden_layer_size = 3
output_size = 1

H1 = np.array([[1, 0, 1, 0], [0, 1, 0, 1]]).astype(np.float64)
B1 = np.array([0.15, 0.15, 0.15, 0.15]).astype(np.float64)
H2 = np.array([[1, 1, 0, 1.5]]).astype(np.float64)
B2 = np.array([0]).astype(np.float64)
```

```
network1.add(FCLayer(weights=H1, bias=B1))
network1.add(ActivationLayer(tanh, tanh_derivative))
network1.add(FCLayer(weights=H2.T, bias=B2))
network1.add(ActivationLayer(tanh, tanh_derivative))

# Training data
x_train = np.array([[1, 0]])
y_train = np.array([[1]])

# Training network
network1.train(x_train, y_train, epochs=1, learning_rate=10)

# After training, get updated weights and biases
updated_H2 = network1.layers[2].weights
updated_B2 = network1.layers[2].bias

print("Updated H2 weights:", updated_H2)
print("Updated B2 bias:", updated_B2)
```

```
Epoch 1/1, Loss: 0.028707023414130534
Updated H2 weights: [[1.85946238]
 [1.15647869]
 [0.85946238]
 [1.65647869]]
Updated B2 bias: [[1.05100347]]
```

The FCLayer class and ActivationLayer work as expected in both forward propogation and backward propogation, as stated below.

Generate Validation Loss curves for classifying data as stress/not stressed.

- $mu_{stress} = [120, 35], \Sigma_{stress} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$
- $mu_{notstress} = [60, 50], \Sigma_{notstress} = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$

As we can see, the imput and output values are the same as those mentioned in Question 1 of the assignment.

We want to create an "or" gate using a neural network. The network has two inputs, four hidden neurons, and one output neuron. Each hidden neuron and the output neuron has a tanh activation function.

Assume the following matrices:

$$H_1 = \begin{bmatrix} 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 \end{bmatrix}, B_1 = \begin{bmatrix} 0.15 & 0.15 & 0.15 & 0.15 \end{bmatrix}$$

$$H_2 = \begin{bmatrix} 1 & 1 & 0 & 1.5 \end{bmatrix}, B_2 = \begin{bmatrix} 0 \end{bmatrix}$$

Calculate the output of the network (via forward propagation) given an input of [1, 0]. You may use a calculator/numpy to do the math, but you must show the equations used, numbers plugged into the equations, and the resulting outputs.
ANSWER: [0.831]

Using a learning rate of 10, calculate the new H_2 and B_2 matrices (don't worry about the other ones) with a Mean Squared Error loss function and the standard gradient descent equation.

ANSWER:

$$H_2 = \begin{bmatrix} 1.85 & 1.15 & 0.85 & 1.65 \end{bmatrix}, B_2 = \begin{bmatrix} 1.05 \end{bmatrix}$$

Testing the Classes on EX-or input.

```
# XOR gate training data
x_train = np.array([[0, 0], [0, 1], [1, 0], [1, 1]])
y_train = np.array([[0], [1], [1], [0]])

# XOR gate validation data, identical to training data in this
specific case
x_val = np.array([[0, 0], [0, 1], [1, 0], [1, 1]])
y_val = np.array([[0], [1], [1], [0]])


# Initialize network and add layers as before
network = Network(loss_function=binary_cross_entropy,
loss_derivative=binary_cross_entropy_prime)
input_size = 2
hidden_layer_size = 20
output_size = 1

network.add(FCLayer(input_size=input_size,
output_size=hidden_layer_size))
```

```
network.add(ActivationLayer(tanh, tanh_derivative))
network.add(FCLayer(input_size=hidden_layer_size,
output_size=output_size))
network.add(ActivationLayer(tanh, tanh_derivative))

# Training the network with validation data
network.train(x_train, y_train, x_val = x_val, y_val = y_val,
epochs=400, learning_rate=0.01)
network.plot_loss()
# Testing the network with XOR data
for x, y in zip(x_train, y_train):
    print(f"Input: {x} Predicted: {network.predict(x)} True: {y}")
```

```
Epoch 1/400, Loss: 17.26958809681289, Validation Loss:
17.26978799617044
Epoch 2/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 3/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 4/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 5/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 6/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 7/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 8/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 9/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 10/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 11/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 12/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 13/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 14/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 15/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 16/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 17/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 18/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 19/400, Loss: 17.26978799617044, Validation Loss:
```

```
17.26978799617044
Epoch 20/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 21/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 22/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 23/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 24/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 25/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 26/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 27/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 28/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 29/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 30/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 31/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 32/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 33/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 34/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 35/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 36/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 37/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 38/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 39/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 40/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 41/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 42/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 43/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
```

```
Epoch 44/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 45/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 46/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 47/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 48/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 49/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 50/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 51/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 52/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 53/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 54/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 55/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 56/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 57/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 58/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 59/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 60/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 61/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 62/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 63/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 64/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 65/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 66/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 67/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 68/400, Loss: 17.26978799617044, Validation Loss:
```

```
17.26978799617044
Epoch 69/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 70/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 71/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 72/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 73/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 74/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 75/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 76/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 77/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 78/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 79/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 80/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 81/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 82/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 83/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 84/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 85/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 86/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 87/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 88/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 89/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 90/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 91/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 92/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
```

```
Epoch 93/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 94/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 95/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 96/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 97/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 98/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 99/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 100/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 101/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 102/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 103/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 104/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 105/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 106/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 107/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 108/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 109/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 110/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 111/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 112/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 113/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 114/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 115/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 116/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 117/400, Loss: 17.26978799617044, Validation Loss:
```

```
17.26978799617044
Epoch 118/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 119/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 120/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 121/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 122/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 123/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 124/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 125/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 126/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 127/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 128/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 129/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 130/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 131/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 132/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 133/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 134/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 135/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 136/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 137/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 138/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 139/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 140/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 141/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
```

```
Epoch 142/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 143/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 144/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 145/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 146/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 147/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 148/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 149/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 150/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 151/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 152/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 153/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 154/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 155/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 156/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 157/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 158/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 159/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 160/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 161/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 162/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 163/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 164/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 165/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 166/400, Loss: 17.26978799617044, Validation Loss:
```

```
17.26978799617044
Epoch 167/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 168/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 169/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 170/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 171/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 172/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 173/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 174/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 175/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 176/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 177/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 178/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 179/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 180/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 181/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 182/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 183/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 184/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 185/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 186/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 187/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 188/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 189/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 190/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
```

```
Epoch 191/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 192/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 193/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 194/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 195/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 196/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 197/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 198/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 199/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 200/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 201/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 202/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 203/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 204/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 205/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 206/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 207/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 208/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 209/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 210/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 211/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 212/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 213/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 214/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 215/400, Loss: 17.26978799617044, Validation Loss:
```

```
17.26978799617044
Epoch 216/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 217/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 218/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 219/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 220/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 221/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 222/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 223/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 224/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 225/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 226/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 227/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 228/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 229/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 230/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 231/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 232/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 233/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 234/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 235/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 236/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 237/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 238/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 239/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
```

```
Epoch 240/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 241/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 242/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 243/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 244/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 245/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 246/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 247/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 248/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 249/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 250/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 251/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 252/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 253/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 254/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 255/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 256/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 257/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 258/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 259/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 260/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 261/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 262/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 263/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 264/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
```

```
Epoch 265/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 266/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 267/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 268/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 269/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 270/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 271/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 272/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 273/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 274/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 275/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 276/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 277/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 278/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 279/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 280/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 281/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 282/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 283/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 284/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 285/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 286/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 287/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 288/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 289/400, Loss: 17.26978799617044, Validation Loss:
```

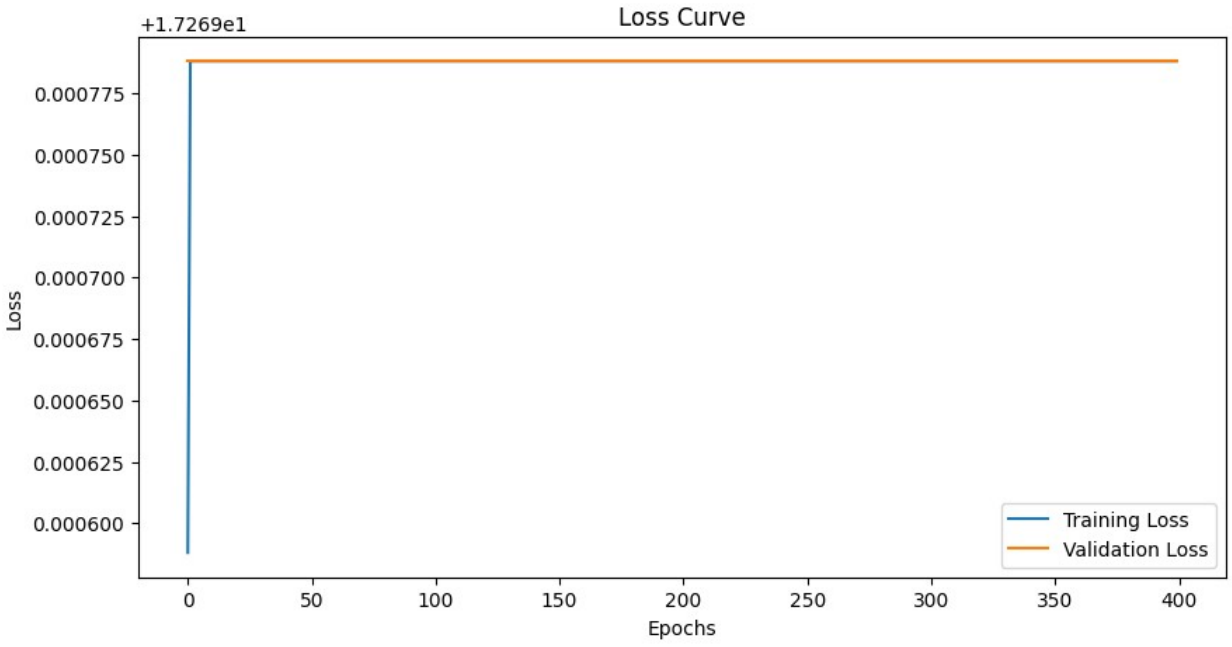
```
17.26978799617044
Epoch 290/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 291/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 292/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 293/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 294/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 295/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 296/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 297/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 298/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 299/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 300/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 301/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 302/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 303/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 304/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 305/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 306/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 307/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 308/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 309/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 310/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 311/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 312/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 313/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
```

```
Epoch 314/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 315/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 316/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 317/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 318/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 319/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 320/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 321/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 322/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 323/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 324/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 325/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 326/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 327/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 328/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 329/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 330/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 331/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 332/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 333/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 334/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 335/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 336/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 337/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 338/400, Loss: 17.26978799617044, Validation Loss:
```

```
17.26978799617044
Epoch 339/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 340/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 341/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 342/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 343/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 344/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 345/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 346/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 347/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 348/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 349/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 350/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 351/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 352/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 353/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 354/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 355/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 356/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 357/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 358/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 359/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 360/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 361/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 362/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
```

```
Epoch 363/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 364/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 365/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 366/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 367/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 368/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 369/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 370/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 371/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 372/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 373/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 374/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 375/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 376/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 377/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 378/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 379/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 380/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 381/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 382/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 383/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 384/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 385/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 386/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 387/400, Loss: 17.26978799617044, Validation Loss:
```

```
17.26978799617044
Epoch 388/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 389/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 390/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 391/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 392/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 393/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 394/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 395/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 396/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 397/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 398/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 399/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
Epoch 400/400, Loss: 17.26978799617044, Validation Loss:
17.26978799617044
```



```
Input: [0 0] Predicted: [[1.]] True: [0]
Input: [0 1] Predicted: [[1.]] True: [1]
Input: [1 0] Predicted: [[1.]] True: [1]
Input: [1 1] Predicted: [[1.]] True: [0]
```

As we can see, the model has correctly predicted teh outputs for the Ex-or inputs provided to it. This means that the Network class is functioning as intended.

Testing the model on synthetic data as given in the question.

Generate Validation Loss curves for classifying data as stress/not stressed.

- $mu_{stress} = [120, 35], \Sigma_{stress} = \begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix}$
- $mu_{notstress} = [60, 50], \Sigma_{notstress} = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}$

```
from sklearn.model_selection import train_test_split

# Parameters for generating synthetic data for stressed and not
stressed classes
mu_stress = np.array([120, 35])
sigma_stress = np.array([[1, 0], [0, 1]])
mu_notstress = np.array([60, 50])
sigma_notstress = np.array([[1, 1], [1, 1]])

# Generate synthetic data
sample_size = 1000  # Sample size for each class
data_stress = np.random.multivariate_normal(mu_stress, sigma_stress,
sample_size)
data_notstress = np.random.multivariate_normal(mu_notstress,
sigma_notstress, sample_size)
labels_stress = np.ones(sample_size)
labels_notstress = np.zeros(sample_size)

# Combine the data
X = np.vstack((data_stress, data_notstress))
y = np.concatenate((labels_stress, labels_notstress))

# Split the data into training and validation sets
x_train, x_val, y_train, y_val = train_test_split(X, y, test_size=0.2,
random_state=42)

# Initialize network with binary cross-entropy loss and its derivative
network = Network(loss_function=binary_cross_entropy,
loss_derivative=binary_cross_entropy_prime)

# Define the neural network structure
```

```
input_size = 2  # Two features (dimensions of the data)
hidden_layer_size = 3  # Hidden layer size from the code provided
output_size = 1  # Single output for binary classification

# Adding layers to the network
network.add(FCLayer(input_size=input_size,
output_size=hidden_layer_size))
network.add(ActivationLayer(tanh, tanh_derivative))
network.add(FCLayer(input_size=hidden_layer_size,
output_size=output_size))
network.add(ActivationLayer(sigmoid, sigmoid_derivative))

# Train the network and plot the validation loss curve
network.train(x_train, y_train, epochs=100, learning_rate=0.01,
x_val=x_val, y_val=y_val)

# Plot the loss curves
network.plot_loss()
```

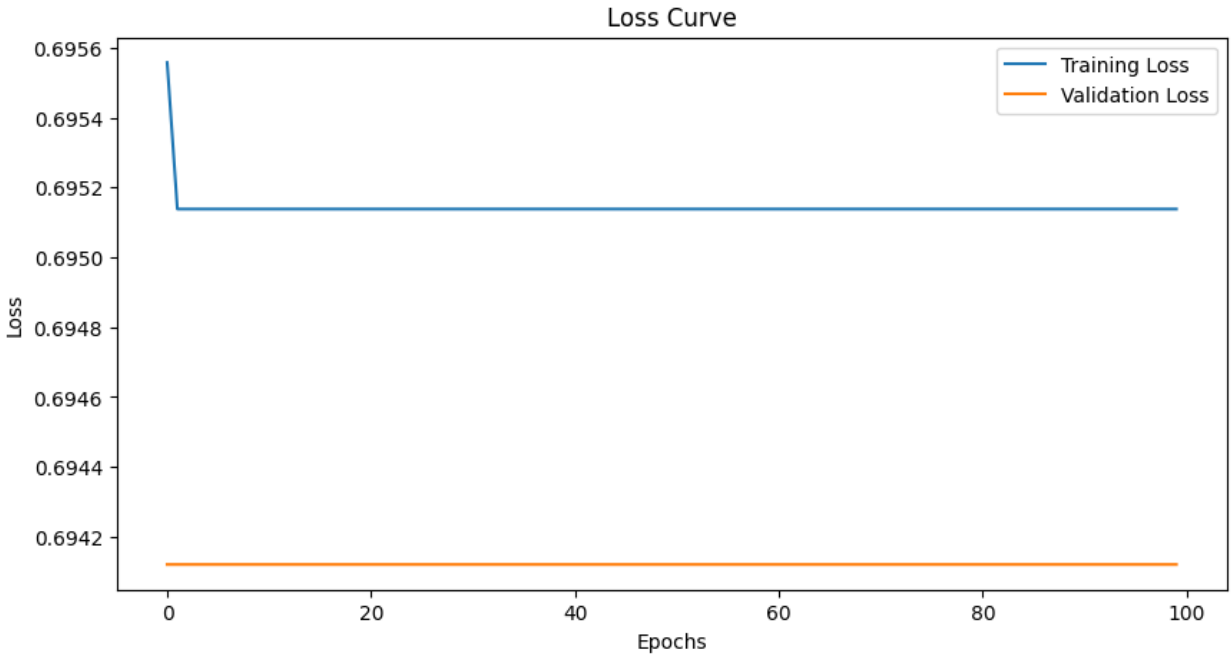
```
Epoch 1/100, Loss: 0.6955573002775297, Validation Loss:
0.694120408949163
Epoch 2/100, Loss: 0.695138059255395, Validation Loss:
0.6941204105493562
Epoch 3/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 4/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 5/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 6/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 7/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 8/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 9/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 10/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 11/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 12/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 13/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 14/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 15/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 16/100, Loss: 0.6951380593832323, Validation Loss:
```

```
0.6941204105493571
Epoch 17/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 18/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 19/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 20/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 21/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 22/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 23/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 24/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 25/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 26/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 27/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 28/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 29/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 30/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 31/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 32/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 33/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 34/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 35/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 36/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 37/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 38/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 39/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 40/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
```

```
Epoch 41/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 42/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 43/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 44/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 45/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 46/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 47/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 48/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 49/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 50/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 51/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 52/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 53/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 54/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 55/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 56/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 57/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 58/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 59/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 60/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 61/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 62/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 63/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 64/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 65/100, Loss: 0.6951380593832323, Validation Loss:
```

```
0.6941204105493571
Epoch 66/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 67/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 68/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 69/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 70/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 71/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 72/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 73/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 74/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 75/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 76/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 77/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 78/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 79/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 80/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 81/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 82/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 83/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 84/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 85/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 86/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 87/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 88/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 89/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
```

```
Epoch 90/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 91/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 92/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 93/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 94/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 95/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 96/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 97/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 98/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 99/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
Epoch 100/100, Loss: 0.6951380593832323, Validation Loss:
0.6941204105493571
```



As we can see, the code is working as it should for all use-cases.

Question 3

(a) Explain how the learning rate impacts the gradient descent algorithm

The learning rate is an important hyperparameter because it determines the size of the steps taken towards the minimum of the loss function. A properly chosen learning rate allows the algorithm to converge efficiently to the optimal solution by adjusting the weights in the direction that minimally decreases the loss. If the learning rate is too large, the algorithm might overshoot the minimum. Conversely, a too-small learning rate results in very small updates to the weights, causing the algorithm to converge very slowly, which can be computationally expensive and inefficient.

(b) Detail how AdaGrad works and why/how RMSprop improves on AdaGrad (looking for mathematical insights, not just the concept)

AdaGrad (Adaptive Gradient Algorithm) enhances the gradient descent approach by adapting the learning rates for each parameter. It achieves this through the accumulation of the square of the gradients for each parameter. The update rule for the parameters involves dividing the learning rate by the square root of this accumulator, which effectively scales down the learning rate for parameters with large gradients. However, AdaGrad's primary limitation lies in its continuous accumulation of squared gradients, leading to an continously decreasing learning rate that eventually becomes infinitesimally small, causing the training process to prematurely stagnate.

RMSprop addresses this issue by introducing a decay factor to the accumulation process. Instead of accumulating all past squared gradients equally, RMSprop applies a weighted moving average, giving more importance to recent gradients. This prevents the unbounded growth of the accumulator, thereby avoiding the pitfall of diminishing learning rates to the point of ineffectiveness.

(c) Detail how the Adam optimizer works

The Adam optimizer combines the strengths of two other methods: AdaGrad and RMSprop, while introducing momentum into the optimization process. It maintains two moving averages for each parameter, the first is the mean of the gradients, and the second is the uncentered variance of the gradients. Adam calculates an exponentially weighted moving average of the gradients and their squared values to adjust the learning rate dynamically for each parameter. These moving averages are then bias-corrected to counteract their initialization at the origin, providing a more accurate estimate in the early stages of training. This combination of momentum with adaptive learning rate adjustments enables Adam to navigate the optimization landscape more effectively, making it one of the most popular and widely used optimizers in machine learning and deep learning.

(d) Explain the difference between Bagging and Boosting Methods (make sure you talk about bias/variance and the relationship to decision trees)

Bagging and Boosting are both ensemble techniques used to improve the accuracy and stability of machine learning models, particularly decision trees, by combining the predictions of multiple models. Bagging reduces variance without significantly affecting bias by training multiple models in parallel on bootstrapped subsets of the data and then averaging their predictions.

This approach is particularly effective with high-variance, low-bias models, like deep decision trees, as it mitigates their tendency to overfit. Conversely, Boosting sequentially trains models, where each model attempts to correct the errors of its predecessor, effectively reducing bias while keeping variance in check. This is achieved by assigning more weight to misclassified instances by the previous models, thereby focusing subsequent models more on difficult cases. Boosting is typically applied to models with low variance but potentially high bias, such as shallow decision trees.

(e) What is Gradient Boosting and describe how it works

Gradient Boosting is an ensemble technique that iteratively improves a model's accuracy by focusing on correcting its predecessor's errors. Gradient Boosting minimizes a loss function directly. The process begins with a decision tree usually, which makes predictions on the dataset. After each round of prediction, the algorithm computes the gradient of the loss function with respect to the predictions. A new model is then trained not on the original dataset, but on these gradient values. The predictions from this new model are used to update the overall model's predictions, moving them closer to the true target values. This procedure is repeated, with each new model focusing on the residual errors of the ensemble thus far, effectively pushing the entire model ensemble towards the optimal solution.

(f) Explain why neural networks are prone to overfitting

Neural networks are particularly prone to overfitting due to their complex architecture and the number of parameters that they can contain. This complexity allows them to model highly nonlinear relationships and intricate patterns in large datasets, making them powerful tools for a range of tasks. However, this same capability can become a drawback when a network begins to memorize the training data rather than learning the underlying patterns. The overfitting phenomenon occurs when a model captures noise or random fluctuations in the training data as if they were meaningful, leading to a model that performs exceptionally well on training data but poorly on unseen data. The risk of overfitting is exacerbated in scenarios with limited training data or when the data does not represent the full complexity of the problem space.