Neural Network Assignment

February 18, 2019

0.0.1 Project: Create a neural network class

Based on previous code examples, develop a neural network class that is able to classify any dataset provided. The class should create objects based on the desired network architecture:

1. Number of inputs
2. Number of hidden layers
3. Number of neurons per layer
4. Number of outputs
5. Learning rate

The class must have the train, and predict functions.

Test the neural network class on the datasets provided below: Use the input data to train the network, and then pass new inputs to predict on. Print the expected label and the predicted label for the input you used. Print the accuracy of the training after predicting on different inputs.

Use matplotlib to plot the error that the train method generates.

Don't forget to install Keras and tensorflow in your environment!

0.0.2 Import the needed Packages

```
In [12]: import numpy as np
         import matplotlib.pyplot as plt

         # Needed for the mnist data
         from keras.datasets import mnist
         from keras.utils import to_categorical
```

0.0.3 Define the class

```
In [13]: from itertools import tee

         def map_architecture(architecture):
             a, b = tee(architecture)
             next(b, None)
             return zip(a, b)
```

In [14]:
```
class NeuralNetwork:

    def __init__(self, architecture, alpha, use_softmax_last = False):
        '''
            layers: List of integers which represents the architecture of the network
            alpha:  Learning rate.
        '''
        # TODO: Initialize the list of weights matrices, then store
        # the network architecture and learning rate
        self.alpha = alpha
        self.layers = architecture
        self.use_softmax_last = use_softmax_last
        # we add 1 to prev to create a bias for each perceptron
        self.weights = np.array([np.random.randn(current, prev + 1) for prev, current

    def __repr__(self):
        # construct and return a string that represents the network
        # architecture
        return "NeuralNetwork: {}".format("-".join(str(l) for l in self.layers))

    def softmax(self, x):
        # applies the softmax function to a set of values

        expX = np.exp(x)
        return expX / expX.sum(axis=1, keepdims=True)

    def sigmoid(self, x):
        # the sigmoid for a given input value

        return 1.0 / (1.0 + np.exp(np.negative(x)))

    def sigmoid_softmax_deriv_rever(self, x):
        # the derivative of the sigmoid

        return x * (1 - x)

    def predict(self, inputs):
        # TODO: Define the predict function
        for i, layer in enumerate(self.weights):
            inputs[-1] = np.array([np.append(layer_input, 1.0) for layer_input in inpu
            if i == len(self.weights) - 1 and self.use_softmax_last:
                layer_outputs = self.softmax(inputs[-1] @ layer.T)
            else:
                layer_outputs = self.sigmoid(inputs[-1] @ layer.T)
            inputs.append(layer_outputs)
        return inputs[-1]

    def train(self, inputs, labels, epochs = 10000, display_update = 100):
```

```python
        # TODO: Define the training step for the network. It should include the forwa
        # steps, the updating of the weights, and it should print the error every 'di
        # It must return the errors so that they can be displayed with matplotlib
        epoch_errors = []

        for epoch in range(epochs):
            # copy the inputs so as not to mutate them, they will be reused in subseq
            epoch_inputs = [np.copy(inputs[0])]

            # forward propagation
            epoch_outputs = self.predict(epoch_inputs)

            # error calculation
            epoch_error = labels - epoch_outputs

            # store error if appropriate
            if epoch % display_update == 0:
                print(np.mean(np.abs(epoch_error)))
                epoch_errors.append(np.mean(np.abs(epoch_error)))

            # initialize the error with the last level
            layer_error = epoch_error * self.sigmoid_softmax_deriv_rever(epoch_output

            # set up the iterators
            it_epoch_inputs = reversed(epoch_inputs)
            next(it_epoch_inputs, None)

            for (layer, layer_outputs) in zip(reversed(self.weights), it_epoch_inputs
                # update the weights for the current layer
                layer += self.alpha * (layer_outputs.T @ layer_error).T

                # calculate the error for the next layer
                layer_error = (layer_error @ layer) * self.sigmoid_softmax_deriv_reve

                # delete the last element in each error array, it is a byproduct of b
                layer_error = np.delete(layer_error, -1, axis=1)

        return epoch_errors

    def get_accuracy(self, predictions, labels):
        inaccurate_n = 0
        inaccurate_list = []
        for i, (prediction, label) in enumerate(zip(predictions, labels)):
            for prediction_item, label_item in zip(prediction, label):
                if label_item == 1 and prediction_item < 0.95:
                    inaccurate_n += 1
                    inaccurate_list.append((i, prediction))
                    break
```

```
                    if label_item == 0 and prediction_item > 0.05:
                        inaccurate_n += 1
                        inaccurate_list.append((i, prediction))
                        break
            inaccurate_rate = (len(predictions) - inaccurate_n) / len(predictions)
            return (inaccurate_rate, inaccurate_list)
```

0.0.4 Test datasets

XOR

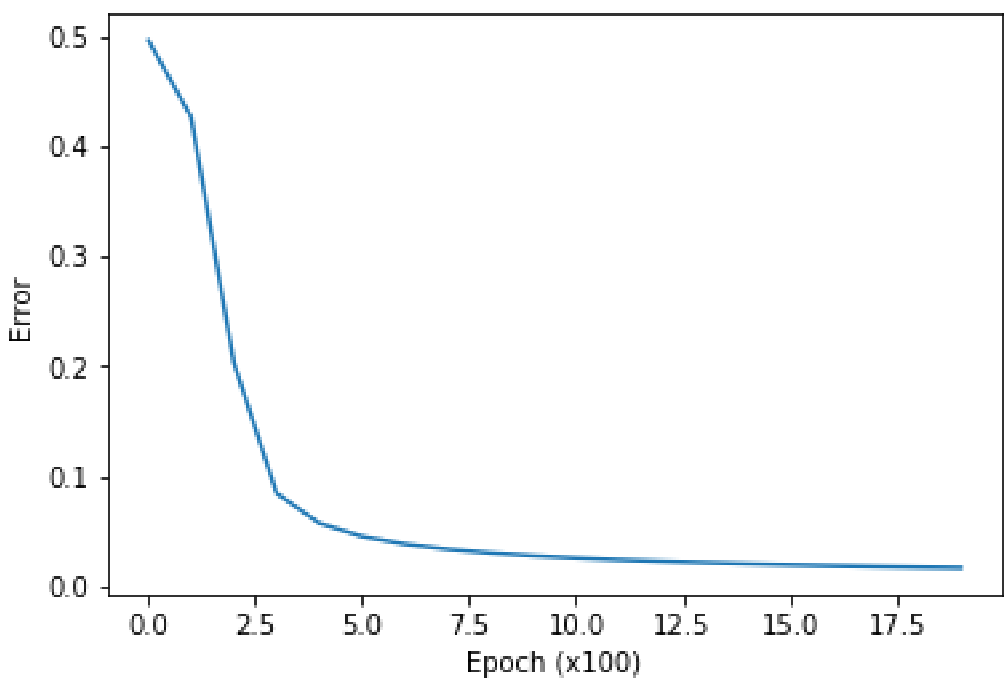
```
In [15]: # input dataset
         XOR_inputs = np.array([
                         [0,0],
                         [0,1],
                         [1,0],
                         [1,1]
                     ])

         # labels dataset
         XOR_labels = np.array([[0,1,1,0]]).T
```

```
In [16]: #TODO: Test the class with the XOR data

         n = NeuralNetwork([2,4,4,1], 1)

         errors = n.train([XOR_inputs], XOR_labels, epochs = 2000, display_update = 100)

         predictions = n.predict([XOR_inputs])
         print('Predictions:')
         print(predictions)

         accuracy = n.get_accuracy(predictions, XOR_labels)

         print('Accuracy:')
         print(str(accuracy[0] * 100) + '%')

         fig, ax = plt.subplots(1,1)
         ax.set_xlabel('Epoch (x100)')
         ax.set_ylabel('Error')
         ax.plot(errors)
```

```
0.4961243035996392
0.4262786560754821
0.20312028838613672
0.08434016101318133
0.057124748000723424
0.04503474924570699
0.038017936240165806
```

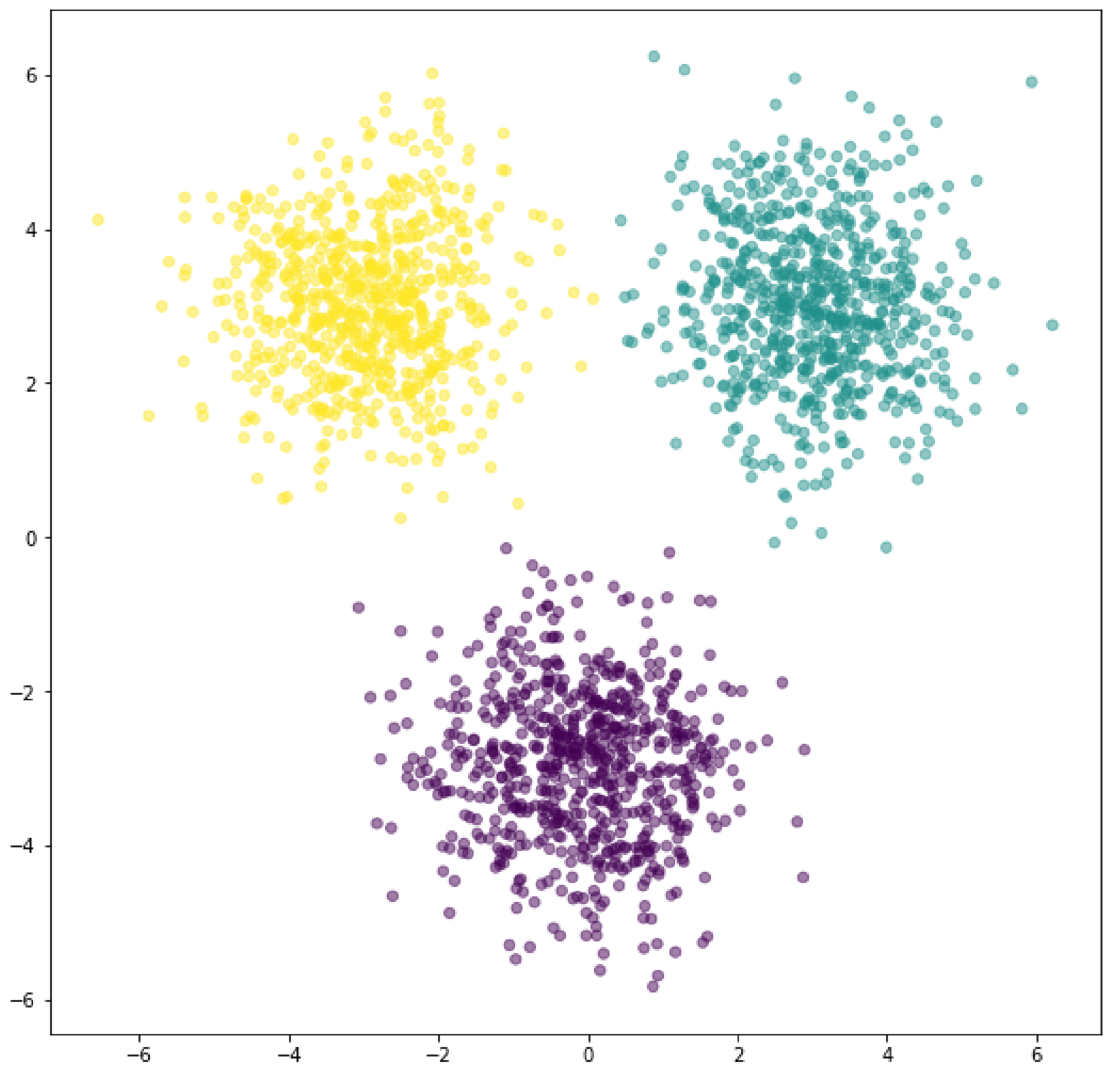
```
0.033351928724552705
0.02998366445109451
0.02741512960034761
0.0253781549494585
0.02371456299946323
0.022324529218745705
0.02114167932528296
0.020120008102152052
0.01922653004271561
0.018436919668952757
0.017732806618270217
0.01710003290258692
0.016527493389798822
Predictions:
[[0.01633554]
 [0.98345726]
 [0.98317887]
 [0.01432596]]
Accuracy:
100.0%
```

Out[16]: [<matplotlib.lines.Line2D at 0x141ce0588>]



Multiple classes

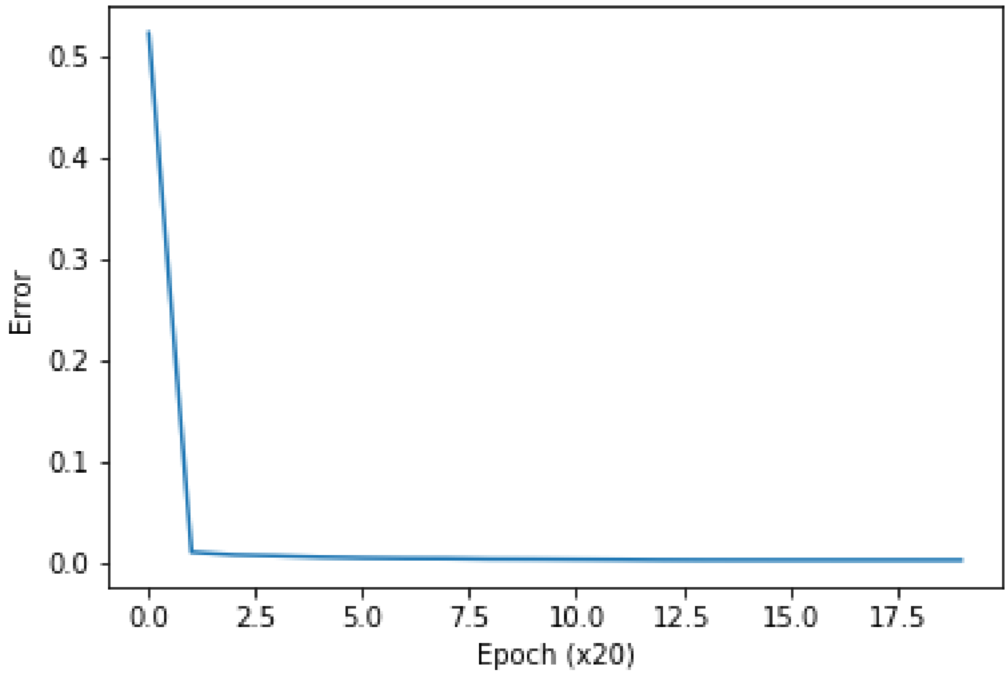
In [17]:
```python
# Creates the data points for each class
class_1 = np.random.randn(700, 2) + np.array([0, -3])
class_2 = np.random.randn(700, 2) + np.array([3, 3])
class_3 = np.random.randn(700, 2) + np.array([-3, 3])

feature_set = np.vstack([class_1, class_2, class_3])

labels = np.array([0]*700 + [1]*700 + [2]*700)

one_hot_labels = np.zeros((2100, 3))

for i in range(2100):
    one_hot_labels[i, labels[i]] = 1

plt.figure(figsize=(10,10))
plt.scatter(feature_set[:,0], feature_set[:,1], c=labels, s=30, alpha=0.5)
plt.show()
```



```
In [18]: # TODO: Test the class with the multiple classes data

         n = NeuralNetwork([2,3], 0.1, use_softmax_last = True)

         errors = n.train([feature_set], one_hot_labels, epochs = 400, display_update = 20)

         predictions = n.predict([feature_set])

         accuracy = n.get_accuracy(predictions, one_hot_labels)

         print('Accuracy:')
         print(str(accuracy[0] * 100) + '%')

         fig, ax = plt.subplots(1,1)
         ax.set_xlabel('Epoch (x20)')
         ax.set_ylabel('Error')
         ax.plot(errors)
```

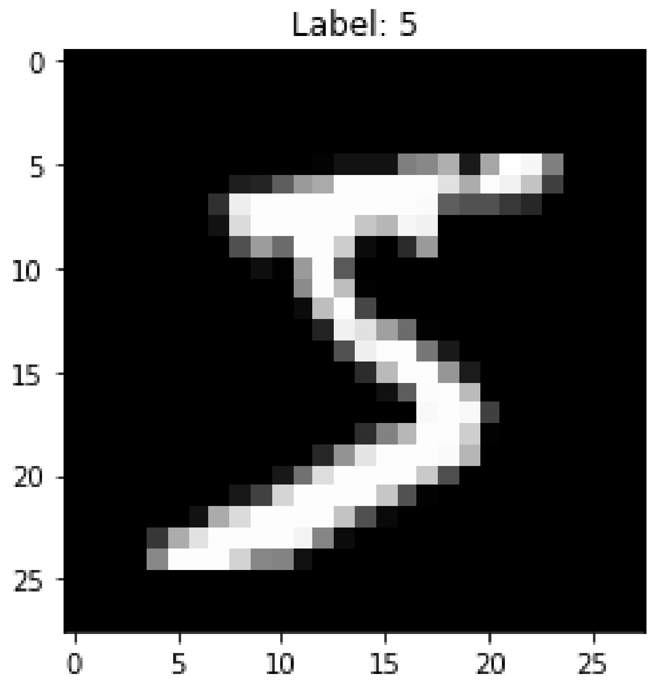
```
0.5227717884970742
0.009599231728164345
0.006910121574483836
0.005960688293858838
0.004675988624526146
0.003941992929325969
0.003515790578854446
0.00336610704791098
0.0027954989663438795
0.002664006564363756
0.002394608012232655
0.002162233582702107
0.0018363057680965342
0.0017268918645751198
0.0017004236635485693
0.0016842299535660952
0.001672301401298084
0.001662646984434509
0.001654282592056404
0.0016465740765556477
Accuracy:
99.66666666666667%
```

```
Out[18]: [<matplotlib.lines.Line2D at 0x141cc9c18>]
```



On the mnist data set

```
In [24]: # Load the train and test data from the mnist data set
         (train_images, train_labels), (test_images, test_labels) = mnist.load_data()

         # Plot a sample data point
         plt.title("Label: " + str(train_labels[0]))
         plt.imshow(train_images[0], cmap="gray")

Out[24]: <matplotlib.image.AxesImage at 0x1324aac50>
```



In [25]:
```
# Standardize the data

# Flatten the images
train_images = train_images.reshape((60000, 28 * 28))
# turn values from 0-255 to 0-1
train_images = train_images.astype('float32') / 255

test_images = test_images.reshape((10000, 28 * 28))
test_images = test_images.astype('float32') / 255

# Create one hot encoding for the labels
train_labels = to_categorical(train_labels)
test_labels = to_categorical(test_labels)
```

In [ ]:
```
# TODO: Test the class with the mnist data. Test the training of the network with the
# record the accuracy of the classification.

n = NeuralNetwork([784,128,64,32,10], 0.001, use_softmax_last = True)

errors = n.train([train_images[0:5000]], train_labels[0:5000], epochs = 2500, display_

predictions = n.predict([test_images])

accuracy = n.get_accuracy(predictions, test_labels)
```

```
        print('Accuracy (without postprocessing):')
        print(str(accuracy[0] * 100) + '%')

        predictions = [[round(prediction_item) for prediction_item in prediction] for predicti

        accuracy = n.get_accuracy(predictions, test_labels)

        print('Accuracy (with postprocessing):')
        print(str(accuracy[0] * 100) + '%')

        fig, ax = plt.subplots(1,1)
        ax.set_xlabel('Epoch (x100)')
        ax.set_ylabel('Error')
        ax.plot(errors)
```

```
0.18068210437341303
0.10660137444930842
0.0690369160963957
0.05198621497706078
0.04169441645361387
0.034795929628618154
0.03003268956316282
0.026405258681094116
0.023544820131677434
0.021232487783874862
0.019371711556151378
0.017859721567282133
0.016557238738031877
0.015454937042368715
0.014502359541974734
0.013664958825069557
0.012915189527332982
0.012258421291386684
0.011618769709223941
0.011061445559467788
0.010580518759267434
0.01015049577197568
0.009750986359004225
0.009381556286274061
0.009001401169356726
```

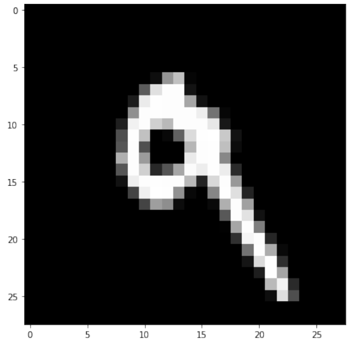
After predicting on the *test_images*, use matplotlib to display some of the images that were not correctly classified. Then, answer the following questions:

1. **Why do you think those were incorrectly classified?**
2. **What could you try doing to improve the classification accuracy?**

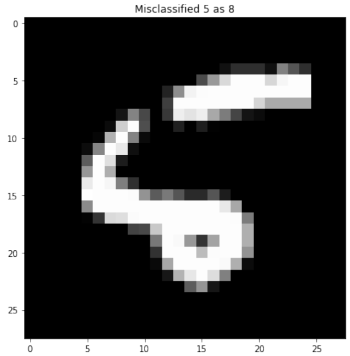
```
In [23]: (train_images, train_labels), (test_images, test_labels) = mnist.load_data()
```

```
image_n = len(accuracy[1])

if len(accuracy[1]) > 5:
    image_n = 5

f, plots = plt.subplots(image_n, 1, figsize=(100,40))

for (prediction, plot) in zip(accuracy[1], plots):
    image = test_images[prediction[0]]
    label = test_labels[prediction[0]]
    wrong_label = prediction[1].index(1.0) if 1.0 in prediction[1] else None
    plot.set_title('Misclassified ' + str(label) + ' as ' + str(wrong_label))
    plot.imshow(image, cmap='gray')
```

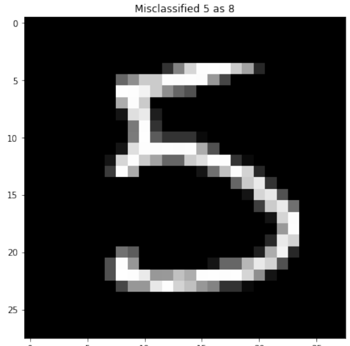
Misclassified 9 as 7



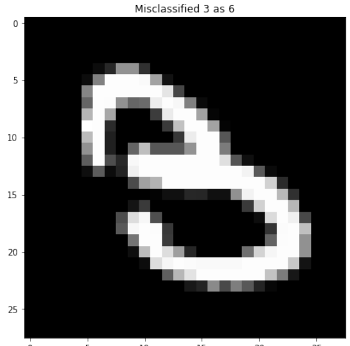
Misclassified 5 as 8



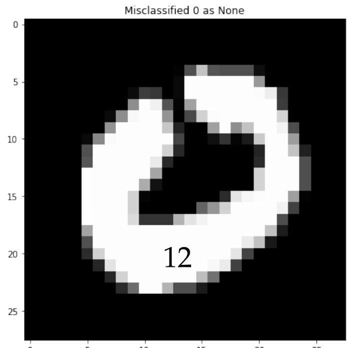
Misclassified 5 as 8



Misclassified 3 as 6



Misclassified 0 as None



1. Why do you think those were incorrectly classified?

Most of those images are badly drawn digits, only recognizable to a human eye thanks to years of experience reading and writing. The neural network only trained with 5000 images, so in these edge cases, it is understandable that it would fail.

2. What could you try doing to improve the classification accuracy?

I would feed the network the entire training set. But in order to do that, I would need to parallelize the network and run it on more appropriate hardware.