Critical Thinking Module 2 Option 1

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CSC 580: Applying Machine Learning and Neural Networks - Capstone

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1) What is the accuracy of the model?

As can be seen in Figure 1, the accuracy of the model was 94.75% after twenty epochs. As can be seen, the model accuracy increases as the number of epochs increases. The accuracy seems to increase faster during the earlier epochs and slower during the later epochs. In fact, the accuracy seems to only marginally increase after the fifteenth epoch.

```
Training epoch 1
Accuracy: 0.8919
Training epoch 2
Accuracy: 0.9112
Training epoch 3
Accuracy: 0.9224
Training epoch 4
Accuracy: 0.9281
Training epoch 5
Accuracy: 0.9319
Training epoch 6
Accuracy: 0.9328
Training epoch 7
Accuracy: 0.9369
Training epoch 8
Accuracy: 0.9365
Training epoch 9
Accuracy: 0.9392
Training epoch 10
Accuracy: 0.9392
Training epoch 11
Accuracy: 0.9425
Training epoch 12
Accuracy: 0.9419
Training epoch 13
Accuracy: 0.9426
Training epoch 14
Accuracy: 0.9451
Training epoch 15
Accuracy: 0.9459
Training epoch 16
Accuracy: 0.9434
Training epoch 17
Accuracy: 0.9451
Training epoch 18
Accuracy: 0.9466
Training epoch 19
Accuracy: 0.9485
Training epoch 20
Accuracy: 0.9475
```

Figure 1: Accuracy of the model over twenty epochs

2) What are some of the misclassified images?

As can be seen in Figure 2, many of the misclassified images have part of the handwritten digit distorted in some way. For example in sample 8, the lower part of the digit is much smaller than expected. In sample 80, the upper part of the digit has curves down. In sample 92, the digit is rotated approximately forty-five degrees. Finally in sample 115, the upper part of the digit is a bit larger than usual.

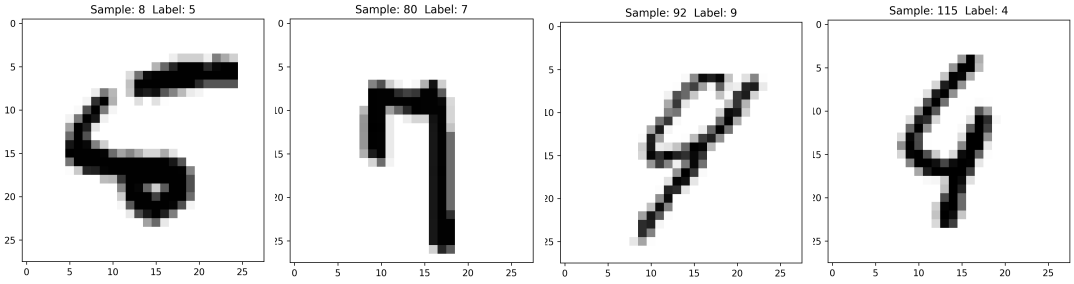

Figure 2: Misclassified images

3) How is the accuracy affected by using more hidden neurons? Fewer hidden neurons?

As can be seen in Figure 3, using only 64 hidden neurons resulted in lower accuracy. Hence, decreasing the amount of hidden neurons decreases the accuracy. Additionally, the training speed was much faster using only 64 hidden neurons compared to 512. As can be seen in Figure 6, using 4096 hidden neurons resulted in higher accuracy. Hence, increasing the amount of hidden neurons increases the accuracy. However, the training speed was much slower using 4096 hidden neurons compared to 512.

```
Training epoch 20
Accuracy: 0.9473
```

Figure 3: Accuracy of training 64 hidden neurons

```
Training epoch 20
Accuracy: 0.9475
```

Figure 4: Accuracy of training 512 hidden neurons

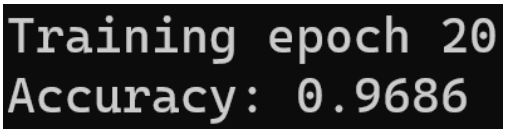

Figure 5: Accuracy of training 4096 hidden neurons

4) How is the accuracy affected by using different learning rates? Try a range of at least four values.

As can be seen in Figure 7, Figure 8, and Figure 9, changing the learning rate between 0.05 to 1 did very little to impact the accuracy of the model. As can be seen in Figure 6, a lower learning rate of 0.005 resulted in a lower accuracy after 20 epochs because the model did not get fully trained. The accuracy may have improved after 20 epochs, but 20 epochs was not long enough to train the 0.005 learning rate. As can be seen in Figure 7, the learning rate that resulted in the best accuracy for twenty epochs was 0.05.

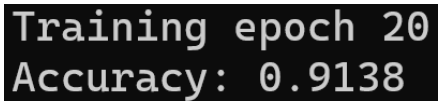

Figure 6: Accuracy after 20 epochs with a learning rate of 0.005

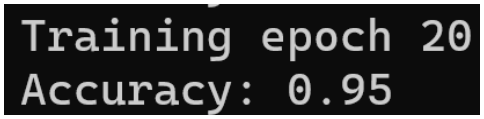

Figure 7: Accuracy after 20 epochs with a learning rate of 0.05

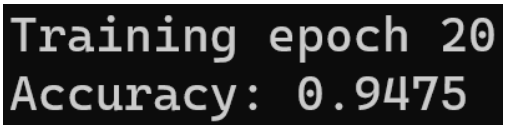

Figure 8: Accuracy after 20 epochs with a learning rate of 0.5

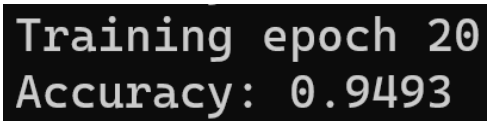

Figure 9: Accuracy after 20 epochs with a learning rate of 1

5) How is accuracy affected by adding another hidden layer?

In the two hidden layer model, my first hidden layer had an output dimensionality of one hundred. The second hidden layer had a dimensionality of ten. As can be seen in Figure 10, accuracy after 20 epochs was much lower with the hidden layers. By adding another layer, the complexity of the model increases. There are more trainable parameters when another hidden layer is added.

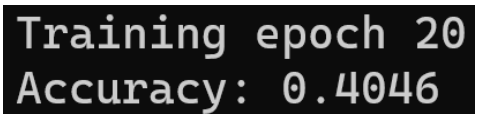

Figure 10: Accuracy at epoch 20 with a second hidden layer

6) How is accuracy affected by using different batch sizes? Try at least three different batch sizes.

As can be seen in Figure 11, Figure 12, Figure 13, and Figure 14, the two smallest batch sizes had the best accuracy and the largest batch size had the worst accuracy. Hence, accuracy seems to improve with smaller batch sizes. However, it seems that as batch size decreases, the training time increases. The smaller batch sizes took much longer to train than the larger batch sizes.

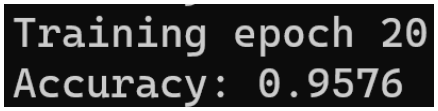

Figure 11: Accuracy after 20 epochs with a batch size of 10

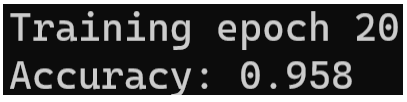

Figure 12: Accuracy after 20 epochs with a batch size of 30

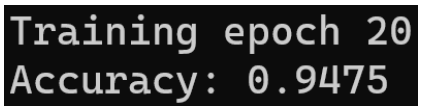

Figure 13: Accuracy after 20 epochs with a batch size of 100

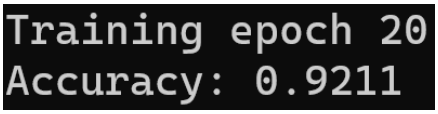

Figure 14: Accuracy after 20 epochs with a batch size of 1000

7) What is the best accuracy you can get from this multi-layer perceptron?

As can be seen in Figure 15, the best accuracy I was able to get from the multi-layer perceptron was 97.48%. I used a learning rate of 0.05, a batch size of 30, and 4096 hidden neurons. The model took a very long time to train, but it resulted in the best accuracy.

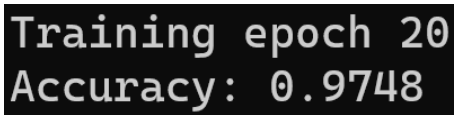

Figure 15: Best accuracy after 20 epochs