Privacy Preserving Decision Tree Prediction On Encrypted Data

Reem Younis, Assia Khateeb, Atheer Abo Foul, Aya Miari
Lecturer : Dr. Adi Akavia
Laboratory in Privacy Preserving Machine Learning, University of Haifa
Email: reembyounis@gmail.com, assia.khteb@gmail.com, 19aether6@gmail.com, aia-m-211@hotmail.com

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Contents

Abstract. In part D we implement the prediction of iris species using perceptron neural networks trained on the Iris data set. It includes write-ups of the different types of perceptrons and their accuracy.

Keywords— Perceptron: either a single-layer or mutli-layer feed-forward neural network.

1 Introduction

Reference to our Github repo.
In part D we'll describe the prediction of iris species using two different perceptron neural networks: a single-layer and multi-layer perceptron.
Each perceptron is trained and evaluated on the Iris data set split into train and test sets.

2 ARCHITECTURE

The main architecture of the neural networks are based on a single-layer perceptron and a multi-layer perceptron.
Each network was trained using the categorical cross entropy loss function, since the problem consists of multiple classes, and the Adam optimizer, due to its practical advantage over alternatives.
The Iris dataset was split beforehand into train and test sets. It consists of samples of 4 features, sepal length, sepal width, petal length, petal width, with 1 of 3 classes, 1.setosa, 2.versicolor, 3.virginica.

3 Single-layer Perceptron

The single-layer perceptron is modeled with an input layer of 4 nodes, one for each feature, and an output layer of 3 nodes, one for each class, with a softmax activation function, since the problem consists of multiple classes.
This was chosen to be a benchmark to see the performance increase with the multi-layer perceptron.
This single-layer perceptron should have a very low accuracy due to its extreme simplicity.

4 Multi-layer Perceptron

The multi-layer perceptron is modeled with an input layer of 4 nodes, one for each feature, 2 hidden layers of 10 nodes with a ReLU activation function, and an output layer of 3 nodes, one for each class, with a softmax activation function, since the problem consists of multiple classes. ReLU was used due to its practical advantage seen in research papers. Theoretically, the 2 hidden layers should be able to learn higher abstract information that the single-layer perceptron could not model. Thus, it is expected to produce a higher accuracy than the single-layer perceptron.

In addition to the change in the network architecture, the multi-layer perceptron also received proprocessed data, that is, data scaled down to the range of -1 to 1. This was done exclusively for the features as the classes are simply represented as a 0 or 1 and thus do not need any scaling. Theoretically, this change should allow the network to train faster as it does not need to give priority to training features that are high in value.

Finally, after each layer in the network, batch normalization was run to further allow the network to train faster and better.

5 RESULTS

```
Epoch 1/100
5/5 [==============================] - 1s 0s/step - loss: 5.1102 - accuracy: 0.3258
Epoch 2/100
5/5 [==============================] - 0s 4ms/step - loss: 5.0277 - accuracy: 0.3258
Epoch 3/100
5/5 [==============================] - 0s 0s/step - loss: 4.9489 - accuracy: 0.3258
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```
Epoch 4/100
5/5 [==============================] - 0s 4ms/step - loss: 4.8675 - accuracy: 0.3258
Epoch 5/100
5/5 [==============================] - 0s 2ms/step - loss: 4.7872 - accuracy: 0.3258
Epoch 6/100
5/5 [==============================] - 0s 0s/step - loss: 4.7102 - accuracy: 0.3258
Epoch 7/100
5/5 [==============================] - 0s 4ms/step - loss: 4.6319 - accuracy: 0.3258
Epoch 8/100
5/5 [==============================] - 0s 0s/step - loss: 4.5566 - accuracy: 0.3258
Epoch 9/100
5/5 [==============================] - 0s 4ms/step - loss: 4.4817 - accuracy: 0.3258
Epoch 10/100
5/5 [==============================] - 0s 0s/step - loss: 4.4088 - accuracy: 0.3258
Epoch 11/100
5/5 [==============================] - 0s 4ms/step - loss: 4.3343 - accuracy: 0.3258
Epoch 12/100
5/5 [==============================] - 0s 0s/step - loss: 4.2627 - accuracy: 0.3258
Epoch 13/100
5/5 [==============================] - 0s 0s/step - loss: 4.1905 - accuracy: 0.3258
Epoch 14/100
5/5 [==============================] - 0s 0s/step - loss: 4.1239 - accuracy: 0.3258
Epoch 15/100
5/5 [==============================] - 0s 0s/step - loss: 4.0564 - accuracy: 0.3258
Epoch 16/100
5/5 [==============================] - 0s 4ms/step - loss: 3.9927 - accuracy: 0.3258
Epoch 17/100
5/5 [==============================] - 0s 0s/step - loss: 3.9270 - accuracy: 0.3258
Epoch 18/100
5/5 [==============================] - 0s 4ms/step - loss: 3.8681 - accuracy: 0.3258
Epoch 19/100
5/5 [==============================] - 0s 2ms/step - loss: 3.8133 - accuracy: 0.3258
Epoch 20/100
5/5 [==============================] - 0s 0s/step - loss: 3.7572 - accuracy: 0.3258
Epoch 21/100
5/5 [==============================] - 0s 0s/step - loss: 3.7059 - accuracy: 0.3258
Epoch 22/100
5/5 [==============================] - 0s 0s/step - loss: 3.6561 - accuracy: 0.3258
Epoch 23/100
5/5 [==============================] - 0s 0s/step - loss: 3.6096 - accuracy: 0.3258
Epoch 24/100
5/5 [==============================] - 0s 0s/step - loss: 3.5600 - accuracy: 0.3258
Epoch 25/100
5/5 [==============================] - 0s 0s/step - loss: 3.5156 - accuracy: 0.3258
Epoch 26/100
5/5 [==============================] - 0s 0s/step - loss: 3.4693 - accuracy: 0.3258
Epoch 27/100
5/5 [==============================] - 0s 0s/step - loss: 3.4267 - accuracy: 0.3258
Epoch 28/100
5/5 [==============================] - 0s 0s/step - loss: 3.3858 - accuracy: 0.3258
Epoch 29/100
5/5 [==============================] - 0s 0s/step - loss: 3.3485 - accuracy: 0.3258
```

```
Epoch 30/100
5/5 [==============================] - 0s 0s/step - loss: 3.3101 - accuracy: 0.3258
Epoch 31/100
5/5 [==============================] - 0s 5ms/step - loss: 3.2757 - accuracy: 0.3258
Epoch 32/100
5/5 [==============================] - 0s 2ms/step - loss: 3.2444 - accuracy: 0.3258
Epoch 33/100
5/5 [==============================] - 0s 2ms/step - loss: 3.2116 - accuracy: 0.3258
Epoch 34/100
5/5 [==============================] - 0s 2ms/step - loss: 3.1833 - accuracy: 0.3333
Epoch 35/100
5/5 [==============================] - 0s 857us/step - loss: 3.1499 - accuracy: 0.3333
Epoch 36/100
5/5 [==============================] - 0s 0s/step - loss: 3.1197 - accuracy: 0.3333
Epoch 37/100
5/5 [==============================] - 0s 0s/step - loss: 3.0895 - accuracy: 0.3333
Epoch 38/100
5/5 [==============================] - 0s 0s/step - loss: 3.0590 - accuracy: 0.3333
Epoch 39/100
5/5 [==============================] - 0s 0s/step - loss: 3.0295 - accuracy: 0.3333
Epoch 40/100
5/5 [==============================] - 0s 4ms/step - loss: 2.9974 - accuracy: 0.3333
Epoch 41/100
5/5 [==============================] - 0s 0s/step - loss: 2.9681 - accuracy: 0.3333
Epoch 42/100
5/5 [==============================] - 0s 0s/step - loss: 2.9407 - accuracy: 0.3409
Epoch 43/100
5/5 [==============================] - 0s 0s/step - loss: 2.9120 - accuracy: 0.3409
Epoch 44/100
5/5 [==============================] - 0s 0s/step - loss: 2.8824 - accuracy: 0.3409
Epoch 45/100
5/5 [==============================] - 0s 0s/step - loss: 2.8530 - accuracy: 0.3409
Epoch 46/100
5/5 [==============================] - 0s 0s/step - loss: 2.8241 - accuracy: 0.3409
Epoch 47/100
5/5 [==============================] - 0s 0s/step - loss: 2.7919 - accuracy: 0.3485
Epoch 48/100
5/5 [==============================] - 0s 4ms/step - loss: 2.7636 - accuracy: 0.3485
Epoch 49/100
5/5 [==============================] - 0s 0s/step - loss: 2.7353 - accuracy: 0.3561
Epoch 50/100
5/5 [==============================] - 0s 0s/step - loss: 2.7091 - accuracy: 0.3561
Epoch 51/100
5/5 [==============================] - 0s 0s/step - loss: 2.6801 - accuracy: 0.3561
Epoch 52/100
5/5 [==============================] - 0s 0s/step - loss: 2.6494 - accuracy: 0.3561
Epoch 53/100
5/5 [==============================] - 0s 0s/step - loss: 2.6184 - accuracy: 0.3561
Epoch 54/100
5/5 [==============================] - 0s 2ms/step - loss: 2.5881 - accuracy: 0.3561
Epoch 55/100
5/5 [==============================] - 0s 0s/step - loss: 2.5570 - accuracy: 0.3561
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Epoch 56/100
5/5 [==============================] - 0s 4ms/step - loss: 2.5264 - accuracy: 0.3636
Epoch 57/100
5/5 [==============================] - 0s 0s/step - loss: 2.4954 - accuracy: 0.3712
Epoch 58/100
5/5 [==============================] - 0s 0s/step - loss: 2.4648 - accuracy: 0.3561
Epoch 59/100
5/5 [==============================] - 0s 0s/step - loss: 2.4381 - accuracy: 0.3561
Epoch 60/100
5/5 [==============================] - 0s 0s/step - loss: 2.4102 - accuracy: 0.3561
Epoch 61/100
5/5 [==============================] - 0s 4ms/step - loss: 2.3837 - accuracy: 0.3636
Epoch 62/100
5/5 [==============================] - 0s 0s/step - loss: 2.3581 - accuracy: 0.3712
Epoch 63/100
5/5 [==============================] - 0s 4ms/step - loss: 2.3293 - accuracy: 0.3712
Epoch 64/100
5/5 [==============================] - 0s 0s/step - loss: 2.3017 - accuracy: 0.3712
Epoch 65/100
5/5 [==============================] - 0s 4ms/step - loss: 2.2719 - accuracy: 0.3712
Epoch 66/100
5/5 [==============================] - 0s 0s/step - loss: 2.2419 - accuracy: 0.3864
Epoch 67/100
5/5 [==============================] - 0s 0s/step - loss: 2.2144 - accuracy: 0.3864
Epoch 68/100
5/5 [==============================] - 0s 0s/step - loss: 2.1865 - accuracy: 0.3864
Epoch 69/100
5/5 [==============================] - 0s 0s/step - loss: 2.1579 - accuracy: 0.3712
Epoch 70/100
5/5 [==============================] - 0s 4ms/step - loss: 2.1304 - accuracy: 0.3712
Epoch 71/100
5/5 [==============================] - 0s 0s/step - loss: 2.1048 - accuracy: 0.3636
Epoch 72/100
5/5 [==============================] - 0s 4ms/step - loss: 2.0768 - accuracy: 0.3561
Epoch 73/100
5/5 [==============================] - 0s 0s/step - loss: 2.0452 - accuracy: 0.3561
Epoch 74/100
5/5 [==============================] - 0s 0s/step - loss: 2.0167 - accuracy: 0.3636
Epoch 75/100
5/5 [==============================] - 0s 0s/step - loss: 1.9872 - accuracy: 0.3636
Epoch 76/100
5/5 [==============================] - 0s 0s/step - loss: 1.9575 - accuracy: 0.3636
Epoch 77/100
5/5 [==============================] - 0s 4ms/step - loss: 1.9277 - accuracy: 0.3864
Epoch 78/100
5/5 [==============================] - 0s 0s/step - loss: 1.8979 - accuracy: 0.3864
Epoch 79/100
5/5 [==============================] - 0s 4ms/step - loss: 1.8672 - accuracy: 0.3864
Epoch 80/100
5/5 [==============================] - 0s 2ms/step - loss: 1.8378 - accuracy: 0.3864
Epoch 81/100
5/5 [==============================] - 0s 0s/step - loss: 1.8088 - accuracy: 0.3864
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Epoch 82/100
5/5 [==============================] - 0s 0s/step - loss: 1.7809 - accuracy: 0.3864
Epoch 83/100
5/5 [==============================] - 0s 0s/step - loss: 1.7501 - accuracy: 0.3864
Epoch 84/100
5/5 [==============================] - 0s 4ms/step - loss: 1.7235 - accuracy: 0.4091
Epoch 85/100
5/5 [==============================] - 0s 0s/step - loss: 1.6962 - accuracy: 0.4167
Epoch 86/100
5/5 [==============================] - 0s 4ms/step - loss: 1.6689 - accuracy: 0.4242
Epoch 87/100
5/5 [==============================] - 0s 0s/step - loss: 1.6422 - accuracy: 0.4394
Epoch 88/100
5/5 [==============================] - 0s 4ms/step - loss: 1.6151 - accuracy: 0.4470
Epoch 89/100
5/5 [==============================] - 0s 0s/step - loss: 1.5876 - accuracy: 0.4470
Epoch 90/100
5/5 [==============================] - 0s 4ms/step - loss: 1.5601 - accuracy: 0.4621
Epoch 91/100
5/5 [==============================] - 0s 0s/step - loss: 1.5331 - accuracy: 0.4621
Epoch 92/100
5/5 [==============================] - 0s 2ms/step - loss: 1.5058 - accuracy: 0.4621
Epoch 93/100
5/5 [==============================] - 0s 0s/step - loss: 1.4769 - accuracy: 0.4470
Epoch 94/100
5/5 [==============================] - 0s 0s/step - loss: 1.4504 - accuracy: 0.4242
Epoch 95/100
5/5 [==============================] - 0s 0s/step - loss: 1.4230 - accuracy: 0.4242
Epoch 96/100
5/5 [==============================] - 0s 0s/step - loss: 1.3961 - accuracy: 0.4242
Epoch 97/100
5/5 [==============================] - 0s 1ms/step - loss: 1.3708 - accuracy: 0.4318
Epoch 98/100
5/5 [==============================] - 0s 998us/step - loss: 1.3444 - accuracy: 0.4470
Epoch 99/100
5/5 [==============================] - 0s 997us/step - loss: 1.3182 - accuracy: 0.4545
Epoch 100/100
5/5 [==============================] - 0s 1ms/step - loss: 1.2951 - accuracy: 0.4545
1/1 [==============================] - 0s 213ms/step - loss: 0.8540 - accuracy: 0.6667
Epoch 1/100
5/5 [==============================] - 1s 4ms/step - loss: 1.8799 - accuracy: 0.2500
Epoch 2/100
5/5 [==============================] - 0s 4ms/step - loss: 1.6343 - accuracy: 0.3258
Epoch 3/100
5/5 [==============================] - 0s 4ms/step - loss: 1.5378 - accuracy: 0.3712
Epoch 4/100
5/5 [==============================] - 0s 0s/step - loss: 1.4903 - accuracy: 0.4242
Epoch 5/100
5/5 [==============================] - 0s 4ms/step - loss: 1.3035 - accuracy: 0.4773
Epoch 6/100
5/5 [==============================] - 0s 4ms/step - loss: 1.2276 - accuracy: 0.5379
Epoch 7/100
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5/5 [==============================] - 0s 0s/step - loss: 1.1522 - accuracy: 0.5379
Epoch 8/100
5/5 [==============================] - 0s 4ms/step - loss: 1.0671 - accuracy: 0.5758
Epoch 9/100
5/5 [==============================] - 0s 0s/step - loss: 1.0572 - accuracy: 0.5379
Epoch 10/100
5/5 [==============================] - 0s 5ms/step - loss: 0.9462 - accuracy: 0.5985
Epoch 11/100
5/5 [==============================] - 0s 2ms/step - loss: 0.9056 - accuracy: 0.5758
Epoch 12/100
5/5 [==============================] - 0s 2ms/step - loss: 0.8131 - accuracy: 0.5985
Epoch 13/100
5/5 [==============================] - 0s 2ms/step - loss: 0.8191 - accuracy: 0.6136
Epoch 14/100
5/5 [==============================] - 0s 2ms/step - loss: 0.7529 - accuracy: 0.6667
Epoch 15/100
5/5 [==============================] - 0s 262us/step - loss: 0.6988 - accuracy: 0.6667
Epoch 16/100
5/5 [==============================] - 0s 4ms/step - loss: 0.6868 - accuracy: 0.6515
Epoch 17/100
5/5 [==============================] - 0s 0s/step - loss: 0.6499 - accuracy: 0.6894
Epoch 18/100
5/5 [==============================] - 0s 4ms/step - loss: 0.5962 - accuracy: 0.7197
Epoch 19/100
5/5 [==============================] - 0s 0s/step - loss: 0.5714 - accuracy: 0.7424
Epoch 20/100
5/5 [==============================] - 0s 0s/step - loss: 0.5506 - accuracy: 0.7576
Epoch 21/100
5/5 [==============================] - 0s 4ms/step - loss: 0.5127 - accuracy: 0.8258
Epoch 22/100
5/5 [==============================] - 0s 4ms/step - loss: 0.5111 - accuracy: 0.8106
Epoch 23/100
5/5 [==============================] - 0s 4ms/step - loss: 0.4799 - accuracy: 0.8333
Epoch 24/100
5/5 [==============================] - 0s 0s/step - loss: 0.4614 - accuracy: 0.8485
Epoch 25/100
5/5 [==============================] - 0s 0s/step - loss: 0.4414 - accuracy: 0.8485
Epoch 26/100
5/5 [==============================] - 0s 4ms/step - loss: 0.4581 - accuracy: 0.8409
Epoch 27/100
5/5 [==============================] - 0s 0s/step - loss: 0.4167 - accuracy: 0.8485
Epoch 28/100
5/5 [==============================] - 0s 4ms/step - loss: 0.4099 - accuracy: 0.8561
Epoch 29/100
5/5 [==============================] - 0s 4ms/step - loss: 0.4126 - accuracy: 0.8712
Epoch 30/100
5/5 [==============================] - 0s 0s/step - loss: 0.3506 - accuracy: 0.8939
Epoch 31/100
5/5 [==============================] - 0s 4ms/step - loss: 0.3735 - accuracy: 0.9015
Epoch 32/100
5/5 [==============================] - 0s 4ms/step - loss: 0.3579 - accuracy: 0.8939
Epoch 33/100
```

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5/5 [==============================] - 0s 0s/step - loss: 0.3769 - accuracy: 0.8939
Epoch 34/100
5/5 [==============================] - 0s 4ms/step - loss: 0.3269 - accuracy: 0.9167
Epoch 35/100
5/5 [==============================] - 0s 0s/step - loss: 0.3213 - accuracy: 0.9091
Epoch 36/100
5/5 [==============================] - 0s 2ms/step - loss: 0.3181 - accuracy: 0.9091
Epoch 37/100
5/5 [==============================] - 0s 0s/step - loss: 0.3084 - accuracy: 0.9318
Epoch 38/100
5/5 [==============================] - 0s 0s/step - loss: 0.3253 - accuracy: 0.9242
Epoch 39/100
5/5 [==============================] - 0s 4ms/step - loss: 0.3335 - accuracy: 0.9167
Epoch 40/100
5/5 [==============================] - 0s 0s/step - loss: 0.2868 - accuracy: 0.9167
Epoch 41/100
5/5 [==============================] - 0s 0s/step - loss: 0.2752 - accuracy: 0.9394
Epoch 42/100
5/5 [==============================] - 0s 4ms/step - loss: 0.2774 - accuracy: 0.9470
Epoch 43/100
5/5 [==============================] - 0s 6ms/step - loss: 0.3153 - accuracy: 0.9091
Epoch 44/100
5/5 [==============================] - 0s 4ms/step - loss: 0.2885 - accuracy: 0.9167
Epoch 45/100
5/5 [==============================] - 0s 0s/step - loss: 0.3074 - accuracy: 0.9318
Epoch 46/100
5/5 [==============================] - 0s 0s/step - loss: 0.2612 - accuracy: 0.9394
Epoch 47/100
5/5 [==============================] - 0s 4ms/step - loss: 0.2433 - accuracy: 0.9394
Epoch 48/100
5/5 [==============================] - 0s 0s/step - loss: 0.2732 - accuracy: 0.9242
Epoch 49/100
5/5 [==============================] - 0s 0s/step - loss: 0.2604 - accuracy: 0.9167
Epoch 50/100
5/5 [==============================] - 0s 4ms/step - loss: 0.2491 - accuracy: 0.9318
Epoch 51/100
5/5 [==============================] - 0s 0s/step - loss: 0.2314 - accuracy: 0.9470
Epoch 52/100
5/5 [==============================] - 0s 2ms/step - loss: 0.2539 - accuracy: 0.9394
Epoch 53/100
5/5 [==============================] - 0s 0s/step - loss: 0.2223 - accuracy: 0.9242
Epoch 54/100
5/5 [==============================] - 0s 4ms/step - loss: 0.2067 - accuracy: 0.9545
Epoch 55/100
5/5 [==============================] - 0s 0s/step - loss: 0.2257 - accuracy: 0.9394
Epoch 56/100
5/5 [==============================] - 0s 0s/step - loss: 0.1948 - accuracy: 0.9697
Epoch 57/100
5/5 [==============================] - 0s 5ms/step - loss: 0.2136 - accuracy: 0.9545
Epoch 58/100
5/5 [==============================] - 0s 2ms/step - loss: 0.2149 - accuracy: 0.9621
Epoch 59/100
```

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5/5 [==============================] - 0s 2ms/step - loss: 0.1907 - accuracy: 0.9621
Epoch 60/100
5/5 [==============================] - 0s 2ms/step - loss: 0.1968 - accuracy: 0.9545
Epoch 61/100
5/5 [==============================] - 0s 2ms/step - loss: 0.1941 - accuracy: 0.9394
Epoch 62/100
5/5 [==============================] - 0s 0s/step - loss: 0.2294 - accuracy: 0.9318
Epoch 63/100
5/5 [==============================] - 0s 4ms/step - loss: 0.2045 - accuracy: 0.9242
Epoch 64/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1784 - accuracy: 0.9545
Epoch 65/100
5/5 [==============================] - 0s 0s/step - loss: 0.1902 - accuracy: 0.9470
Epoch 66/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1882 - accuracy: 0.9470
Epoch 67/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1751 - accuracy: 0.9621
Epoch 68/100
5/5 [==============================] - 0s 0s/step - loss: 0.1750 - accuracy: 0.9394
Epoch 69/100
5/5 [==============================] - 0s 0s/step - loss: 0.1843 - accuracy: 0.9470
Epoch 70/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1715 - accuracy: 0.9545
Epoch 71/100
5/5 [==============================] - 0s 2ms/step - loss: 0.2200 - accuracy: 0.9242
Epoch 72/100
5/5 [==============================] - 0s 0s/step - loss: 0.1641 - accuracy: 0.9697
Epoch 73/100
5/5 [==============================] - 0s 0s/step - loss: 0.1988 - accuracy: 0.9470
Epoch 74/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1971 - accuracy: 0.9470
Epoch 75/100
5/5 [==============================] - 0s 0s/step - loss: 0.1560 - accuracy: 0.9621
Epoch 76/100
5/5 [==============================] - 0s 0s/step - loss: 0.1892 - accuracy: 0.9470
Epoch 77/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1928 - accuracy: 0.9545
Epoch 78/100
5/5 [==============================] - 0s 0s/step - loss: 0.1630 - accuracy: 0.9697
Epoch 79/100
5/5 [==============================] - 0s 0s/step - loss: 0.1838 - accuracy: 0.9545
Epoch 80/100
5/5 [==============================] - 0s 6ms/step - loss: 0.1537 - accuracy: 0.9621
Epoch 81/100
5/5 [==============================] - 0s 0s/step - loss: 0.1483 - accuracy: 0.9697
Epoch 82/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1469 - accuracy: 0.9621
Epoch 83/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1927 - accuracy: 0.9470
Epoch 84/100
5/5 [==============================] - 0s 0s/step - loss: 0.1749 - accuracy: 0.9545
Epoch 85/100
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```
5/5 [==============================] - 0s 0s/step - loss: 0.1645 - accuracy: 0.9545
Epoch 86/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1411 - accuracy: 0.9545
Epoch 87/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1450 - accuracy: 0.9773
Epoch 88/100
5/5 [==============================] - 0s 0s/step - loss: 0.1746 - accuracy: 0.9545
Epoch 89/100
5/5 [==============================] - 0s 2ms/step - loss: 0.1279 - accuracy: 0.9697
Epoch 90/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1316 - accuracy: 0.9848
Epoch 91/100
5/5 [==============================] - 0s 0s/step - loss: 0.1670 - accuracy: 0.9470
Epoch 92/100
5/5 [==============================] - 0s 0s/step - loss: 0.1805 - accuracy: 0.9318
Epoch 93/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1345 - accuracy: 0.9621
Epoch 94/100
5/5 [==============================] - 0s 0s/step - loss: 0.1790 - accuracy: 0.9545
Epoch 95/100
5/5 [==============================] - 0s 0s/step - loss: 0.1490 - accuracy: 0.9621
Epoch 96/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1435 - accuracy: 0.9394
Epoch 97/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1634 - accuracy: 0.9470
Epoch 98/100
5/5 [==============================] - 0s 0s/step - loss: 0.1682 - accuracy: 0.9470
Epoch 99/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1984 - accuracy: 0.9167
Epoch 100/100
5/5 [==============================] - 0s 4ms/step - loss: 0.1511 - accuracy: 0.9470
1/1 [==============================] - 0s 250ms/step - loss: 0.2106 - accuracy: 0.9333

Naive Accuracy:  0.6666666865348816

Naive Predictions:
 [[0.01354977 0.5061691  0.48028105]
 [0.06246578 0.56894875 0.36858547]
 [0.0074184  0.44270876 0.5498728 ]
 [0.01080847 0.4541977  0.53499377]
 [0.02312316 0.55372    0.4231569 ]
 [0.00527738 0.39130107 0.60342157]
 [0.00576249 0.52103436 0.4732032 ]
 [0.00304265 0.31141222 0.68554515]
 [0.07634713 0.58648854 0.33716434]
 [0.00298612 0.3317028  0.6653111 ]
 [0.00340858 0.28069374 0.7158977 ]
 [0.01619304 0.5350266  0.44878045]
 [0.00580444 0.32919884 0.66499674]
 [0.01750648 0.56174    0.4207535 ]
 [0.00643218 0.49766505 0.49590284]]
```

```
Better Accuracy:  0.9333333373069763

Better Predictions:
 [[0.00862633 0.9620326  0.02934105]
 [0.9790445  0.01505063 0.00590489]
 [0.00578253 0.9523178  0.0418997 ]
 [0.00888783 0.97394866 0.01716346]
 [0.07783689 0.7403439  0.18181916]
 [0.01994696 0.21152395 0.7685291 ]
 [0.0148526  0.86186147 0.12328597]
 [0.00590803 0.02657974 0.96751225]
 [0.9846364  0.0105518  0.00481179]
 [0.00601991 0.05104782 0.94293225]
 [0.00143864 0.0452151  0.95334625]
 [0.01584265 0.9249697  0.0591877 ]
 [0.01459309 0.3523831  0.63302374]
 [0.01764467 0.9287313  0.05362389]
 [0.01701402 0.77023745 0.21274848]]
```

As seen in the example run, the multi-layer perceptron performed much better than the single-layer perceptron. The accuracy for the single-layer perceptron and multi-layer perceptron was 66.666% and 93.333%, respectively.

Thus, it can easily be stated that the hidden layers and preprocessing of data allowed the multi-layer perceptron to much better learn the data.

The 2 hidden layers allowed the multi-layer perceptron to learn higher abstract features about the Iris data set and thus produced a higher accuracy. Furthermore, the data scaling and batch normalization increased the network's learning rate.

Although a 93.333% accuracy is astounding, this is not likely to continue if the test data set size increased.

6 Conclusions

Overall, the results gathered follow the expectation/hypothesis, that is, that a more complex network, but not too complex, would be able to learn much more effectively than a simple one. This is likely in many scenarios.

However, it is likely that the bias-variance tradeoff effect would come into play here. That is, as the bias of a model increases, its variance will as well, and vise-versa. A simple model has extreme bias, but no variance.

A extremely complex model has high variance, but almost no bias. Thus, an extremely complex model is likely to overfit a data set, while a simple model is likely to underfit a data set.

Therefore, it is evident that caution must be taken to find a point where the bias and variance are minimized while still producing an effective model.

This can be done by using a technique like cross-validation to produce models that are each trained and validated against different "folds" of the train data set. Then, the model that minimizes the loss function (against the sum of error of the validation folds) can be used as the final model and can be run on the test set to produce the resulting accuracy.

7 Platforms

- pycharm, python 3.9
- overleaf.com