Models:

Model: "sequential"

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Layer (type) Output Shape Param #

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conv2d (Conv2D) (None, 32, 32, 256) 7168

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batch\_normalization (BatchNo (None, 32, 32, 256) 1024

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conv2d\_1 (Conv2D) (None, 32, 32, 256) 590080

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batch\_normalization\_1 (Batch (None, 32, 32, 256) 1024

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dropout (Dropout) (None, 32, 32, 256) 0

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max\_pooling2d (MaxPooling2D) (None, 16, 16, 256) 0

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conv2d\_2 (Conv2D) (None, 16, 16, 128) 295040

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batch\_normalization\_2 (Batch (None, 16, 16, 128) 512

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conv2d\_3 (Conv2D) (None, 16, 16, 128) 147584

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batch\_normalization\_3 (Batch (None, 16, 16, 128) 512

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dropout\_1 (Dropout) (None, 16, 16, 128) 0

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max\_pooling2d\_1 (MaxPooling2 (None, 8, 8, 128) 0

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conv2d\_4 (Conv2D) (None, 8, 8, 64) 73792

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batch\_normalization\_4 (Batch (None, 8, 8, 64) 256

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conv2d\_5 (Conv2D) (None, 8, 8, 64) 36928

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batch\_normalization\_5 (Batch (None, 8, 8, 64) 256

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dropout\_2 (Dropout) (None, 8, 8, 64) 0

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max\_pooling2d\_2 (MaxPooling2 (None, 4, 4, 64) 0

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conv2d\_6 (Conv2D) (None, 4, 4, 32) 18464

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batch\_normalization\_6 (Batch (None, 4, 4, 32) 128

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conv2d\_7 (Conv2D) (None, 4, 4, 32) 9248

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batch\_normalization\_7 (Batch (None, 4, 4, 32) 128

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dropout\_3 (Dropout) (None, 4, 4, 32) 0

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flatten (Flatten) (None, 512) 0

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dense (Dense) (None, 64) 32832

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batch\_normalization\_8 (Batch (None, 64) 256

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dense\_1 (Dense) (None, 32) 2080

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batch\_normalization\_9 (Batch (None, 32) 128

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dense\_2 (Dense) (None, 16) 528

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batch\_normalization\_10 (Batc (None, 16) 64

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dense\_3 (Dense) (None, 10) 170

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dropout\_4 (Dropout) (None, 10) 0

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Total params: 1,218,202

Trainable params: 1,216,058

Non-trainable params: 2,144

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313/313 - 3s - loss: 0.5103 - accuracy: 0.8545

[0.5102857947349548, 0.8544999957084656]

CPU times: user 13min 33s, sys: 4min 53s, total: 18min 27s

Wall time: 22min 24s

Summary (Final model GPU):

Final model yielded an accuracy of 85.45% but varied on multiple runs demonstrated an accuracy between 84-85% typically with a lost of .5103% of the data overall. It consisted of 8 convolutional steps with a Batch Normalization step following each. Each Batch Normalization was followed by a Dropout layer of 20% then a Maxpooling layer specified as 2,2. Four non-convolutional layers were also utilized and followed by a Batch Normalization with the exception of the last non-convolutional layer which was instead followed by an additional dropout layer of 20%. The ‘elu’ activation option was used for all convolutional and non-convolutional layers of the model. The model is set to run for a maximum of 100 epochs but was stopped often before using an early stop measure to prevent any overfitting. The model is saved as Mobley\_model.h5 and was ran using a GPU.

Model: "sequential"

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Layer (type) Output Shape Param #

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conv2d (Conv2D) (None, 32, 32, 256) 7168

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batch\_normalization (BatchNo (None, 32, 32, 256) 1024

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conv2d\_1 (Conv2D) (None, 32, 32, 256) 590080

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batch\_normalization\_1 (Batch (None, 32, 32, 256) 1024

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dropout (Dropout) (None, 32, 32, 256) 0

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max\_pooling2d (MaxPooling2D) (None, 16, 16, 256) 0

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conv2d\_2 (Conv2D) (None, 16, 16, 128) 295040

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batch\_normalization\_2 (Batch (None, 16, 16, 128) 512

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conv2d\_3 (Conv2D) (None, 16, 16, 128) 147584

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batch\_normalization\_3 (Batch (None, 16, 16, 128) 512

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dropout\_1 (Dropout) (None, 16, 16, 128) 0

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max\_pooling2d\_1 (MaxPooling2 (None, 8, 8, 128) 0

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conv2d\_4 (Conv2D) (None, 8, 8, 64) 73792

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batch\_normalization\_4 (Batch (None, 8, 8, 64) 256

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conv2d\_5 (Conv2D) (None, 8, 8, 64) 36928

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batch\_normalization\_5 (Batch (None, 8, 8, 64) 256

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dropout\_2 (Dropout) (None, 8, 8, 64) 0

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max\_pooling2d\_2 (MaxPooling2 (None, 4, 4, 64) 0

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conv2d\_6 (Conv2D) (None, 4, 4, 32) 18464

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batch\_normalization\_6 (Batch (None, 4, 4, 32) 128

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conv2d\_7 (Conv2D) (None, 4, 4, 32) 9248

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batch\_normalization\_7 (Batch (None, 4, 4, 32) 128

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dropout\_3 (Dropout) (None, 4, 4, 32) 0

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flatten (Flatten) (None, 512) 0

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dense (Dense) (None, 64) 32832

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batch\_normalization\_8 (Batch (None, 64) 256

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dense\_1 (Dense) (None, 32) 2080

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batch\_normalization\_9 (Batch (None, 32) 128

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dense\_2 (Dense) (None, 16) 528

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batch\_normalization\_10 (Batc (None, 16) 64

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dense\_3 (Dense) (None, 10) 170

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dropout\_4 (Dropout) (None, 10) 0

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Total params: 1,218,202

Trainable params: 1,216,058

Non-trainable params: 2,144

1563/1563 [==============================] - 4931s 3s/step - loss: 1.8240 - accuracy: 0.3625 - val\_loss: 1.2235 - val\_accuracy: 0.5974

CPU times: user 2h 40min 10s, sys: 58.3 s, total: 2h 41min 8s

Wall time: 1h 22min 11s

Summary (Final Model CPU):

The final model when ran on the CPU compared to the GPU took over an hour to complete a single epoch. This is astronomically longer than what it took when using a GPU surpassing the entire GPU run time of up to 100 epochs by roughly two hours. Since the GPU model was typically stopped to prevent overfitting around epochs 22-23 we could assume it would likely take an entire day to run through this entire model without a GPU to process it. The accuracy is nothing to speak of because it was only given 1 epoch to train as such it would be unfair to give a comparison but despite this it was represented with a values of 59.74% with a loss rate of 1.22% roughly.

Model: "sequential"

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Layer (type) Output Shape Param #

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conv2d (Conv2D) (None, 32, 32, 32) 896

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batch\_normalization (BatchNo (None, 32, 32, 32) 128

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conv2d\_1 (Conv2D) (None, 32, 32, 32) 9248

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dropout (Dropout) (None, 32, 32, 32) 0

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max\_pooling2d (MaxPooling2D) (None, 16, 16, 32) 0

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conv2d\_2 (Conv2D) (None, 16, 16, 64) 18496

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batch\_normalization\_1 (Batch (None, 16, 16, 64) 256

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conv2d\_3 (Conv2D) (None, 16, 16, 64) 36928

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dropout\_1 (Dropout) (None, 16, 16, 64) 0

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max\_pooling2d\_1 (MaxPooling2 (None, 8, 8, 64) 0

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conv2d\_4 (Conv2D) (None, 8, 8, 128) 73856

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batch\_normalization\_2 (Batch (None, 8, 8, 128) 512

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conv2d\_5 (Conv2D) (None, 8, 8, 128) 147584

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dropout\_2 (Dropout) (None, 8, 8, 128) 0

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flatten (Flatten) (None, 8192) 0

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dense (Dense) (None, 128) 1048704

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dense\_1 (Dense) (None, 10) 1290

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Total params: 1,337,898

Trainable params: 1,337,450

Non-trainable params: 448

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313/313 - 1s - loss: 0.7939 - accuracy: 0.8004

[0.7939211130142212, 0.8004000186920166]

CPU times: user 2min 29s, sys: 18.5 s, total: 2min 47s

Wall time: 2min 25s

Summary (80% model GPU):

This model yielded an accuracy of 80.04% but often varied between 78-80% based on multiple runs. with a loss of .7939% of the data. It consisted of 6 convolutional steps with a Batch Normalization step following every other convolutional layer .Dropout layers were included using a rate of 20% after every two convolutional layers as well as Maxpooling layers set to 2,2. Two non-convolutional layers were also utilized, all convolutional layers utilized the ‘relu’ activation option with the exception of the very last non-convolutional layer which utilized the softmax step. The model was trained on 15 epochs using the adam optimizer and is saved as Mobley\_model80.h5 and was ran using a GPU.

Model: "sequential"

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Layer (type) Output Shape Param #

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conv2d (Conv2D) (None, 32, 32, 32) 896

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batch\_normalization (BatchNo (None, 32, 32, 32) 128

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conv2d\_1 (Conv2D) (None, 32, 32, 32) 9248

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dropout (Dropout) (None, 32, 32, 32) 0

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max\_pooling2d (MaxPooling2D) (None, 16, 16, 32) 0

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conv2d\_2 (Conv2D) (None, 16, 16, 64) 18496

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batch\_normalization\_1 (Batch (None, 16, 16, 64) 256

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conv2d\_3 (Conv2D) (None, 16, 16, 64) 36928

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dropout\_1 (Dropout) (None, 16, 16, 64) 0

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max\_pooling2d\_1 (MaxPooling2 (None, 8, 8, 64) 0

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conv2d\_4 (Conv2D) (None, 8, 8, 128) 73856

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batch\_normalization\_2 (Batch (None, 8, 8, 128) 512

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conv2d\_5 (Conv2D) (None, 8, 8, 128) 147584

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dropout\_2 (Dropout) (None, 8, 8, 128) 0

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flatten (Flatten) (None, 8192) 0

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dense (Dense) (None, 128) 1048704

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dense\_1 (Dense) (None, 10) 1290

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Total params: 1,337,898

Trainable params: 1,337,450

Non-trainable params: 448

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313/313 - 17s - loss: 1.1685 - accuracy: 0.5980

[1.168473482131958, 0.5979999899864197]

CPU times: user 13min 16s, sys: 18.8 s, total: 13min 35s

Wall time: 7min 14s

Summary (80% Model CPU):

Based on 1 epoch it took the model a total of roughly 7 minutes to reach completion if this were to hold true and ran to the remainder of epochs as done for the GPU model then this model would take significantly longer than it did to reach completion. Not much can be said about the accuracy after one epoch but it is noticeably lower than that of the GPU model when it reached its completion.

Model: "sequential"

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Layer (type) Output Shape Param #

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conv2d (Conv2D) (None, 32, 32, 32) 896

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conv2d\_1 (Conv2D) (None, 32, 32, 32) 9248

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dropout (Dropout) (None, 32, 32, 32) 0

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max\_pooling2d (MaxPooling2D) (None, 16, 16, 32) 0

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conv2d\_2 (Conv2D) (None, 16, 16, 64) 18496

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conv2d\_3 (Conv2D) (None, 16, 16, 64) 36928

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dropout\_1 (Dropout) (None, 16, 16, 64) 0

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max\_pooling2d\_1 (MaxPooling2 (None, 8, 8, 64) 0

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conv2d\_4 (Conv2D) (None, 8, 8, 128) 73856

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conv2d\_5 (Conv2D) (None, 8, 8, 128) 147584

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dropout\_2 (Dropout) (None, 8, 8, 128) 0

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flatten (Flatten) (None, 8192) 0

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dense (Dense) (None, 32) 262176

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dense\_1 (Dense) (None, 28) 924

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dense\_2 (Dense) (None, 10) 290

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Total params: 550,398

Trainable params: 550,398

Non-trainable params: 0

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313/313 - 1s - loss: 0.7515 - accuracy: 0.7658

[0.7515157461166382, 0.7657999992370605]

CPU times: user 2min 19s, sys: 19 s, total: 2min 38s

Wall time: 2min 47s

Summary (77% model GPU):

Model consists of 6 convolutional layers utilizing a dropout of 20% and maxpooling layer of 2,2 between every two convolutional layers. 3 non convolutional layers are included in the model and the activation option is set to ‘relu’. The model had an overall accuracy rate of 76.58% but often varied based on multiple runs was found to be between between 75-77% and a loss rate of .7515%. It is saved as Mobley\_model77.h5 and was ran using a GPU.

Model: "sequential"

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Layer (type) Output Shape Param #

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conv2d (Conv2D) (None, 32, 32, 32) 896

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conv2d\_1 (Conv2D) (None, 32, 32, 32) 9248

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dropout (Dropout) (None, 32, 32, 32) 0

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max\_pooling2d (MaxPooling2D) (None, 16, 16, 32) 0

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conv2d\_2 (Conv2D) (None, 16, 16, 64) 18496

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conv2d\_3 (Conv2D) (None, 16, 16, 64) 36928

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dropout\_1 (Dropout) (None, 16, 16, 64) 0

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max\_pooling2d\_1 (MaxPooling2 (None, 8, 8, 64) 0

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conv2d\_4 (Conv2D) (None, 8, 8, 128) 73856

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conv2d\_5 (Conv2D) (None, 8, 8, 128) 147584

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dropout\_2 (Dropout) (None, 8, 8, 128) 0

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flatten (Flatten) (None, 8192) 0

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dense (Dense) (None, 32) 262176

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dense\_1 (Dense) (None, 28) 924

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dense\_2 (Dense) (None, 10) 290

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Total params: 550,398

Trainable params: 550,398

Non-trainable params: 0

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313/313 - 16s - loss: 1.4008 - accuracy: 0.5070

[1.4008229970932007, 0.5070000290870667]

CPU times: user 12min 20s, sys: 18.9 s, total: 12min 39s

Wall time: 6min 48s

Summary (77% model CPU):

Model attained an accuracy of roughly 50% and took 6 minutes to complete one epoch. This means it took nearly three times as long to complete one epoch compared to the GPU models ability to complete all epochs within roughly 2 minutes. The amount of information lost is significantly increased as well.

Conclusions:

Overall, the model seems to benefit greatly from the addition of Dropout and Batch Normalization layers, as well as the addition of more Conv2D and Dense layers in the neural network. As I added more layers and provided them a sort of funneling affect regarding the number of nodes in each layer the accuracy seemed to increase. Also compared to relu, elu seemed to be the better fit for the model in all. Increasing the number of epochs ran on the model was of benefit as well as it allowed for more training for the model and thus greater accuracy. It should be noted however that simply increasing the number of epochs has the potential to result in the overtraining of the model which can hurt the general effectiveness of the model. As such adding the earlystop measure from keras to the final model helped me to ensure this was not something to be concerned with while it still allowed for sufficient time for the model to train. Lastly, as I trained my model’s I noticed differences in the overall accuracy on each successive training session when all epochs concluded. This is certainly due to the variation in the random selection of training data for each epoch and as such I think it would be most appropriate to include a range of accuracies to each model based on this fact.