ASSIGNMENT 2 REPORT

CONVULUTION NEURAL NETWORKS

ADVANCED MACHINE LEARNING

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1. Consider the Cats & Dogs example. Start initially with a training sample of 1000, a validation sample of 500, and a test sample of 500 (like in the text). Use any technique to reduce overfitting and improve performance in developing a network that you train from scratch. What performance did you achieve?

2. Increase your training sample size. You may pick any amount. Keep the validation and test samples the same as above. Optimize your network (again training from scratch). What performance did you achieve?

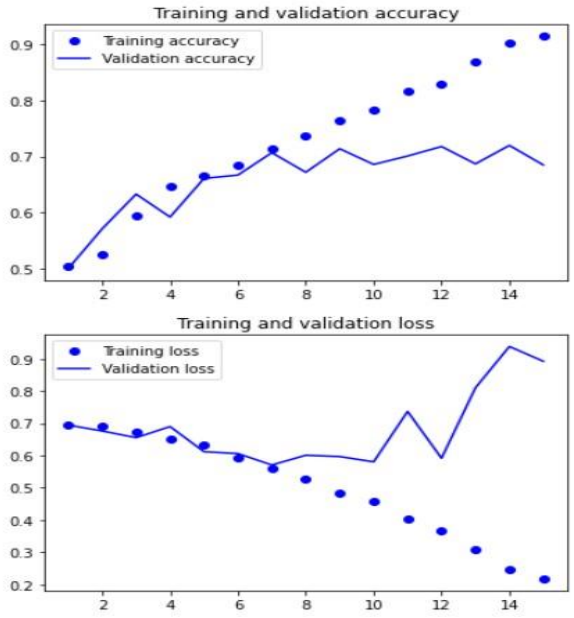
3. Now change your training sample so that you achieve better performance than those from Steps 1 and 2. This sample size may be larger, or smaller than those in the previous steps. The objective is to find the ideal training sample size to get best prediction results.

4. Repeat Steps 1-3, but now using a pretrained network. The sample sizes you use in Steps 2 and 3 for the pretrained network may be the same or different from those using the network where you trained from scratch. Again, use any and all optimization techniques to get best performance.

1: Initial training the model using 15 epochs and without Drop-out and Augmentation

Epochs	Batch Size	Drop-Out	Augmentation	Max pooling	Training Samples	Validation Accuracy	Test Accuracy
15	32	-	-	2	1000	72.0	70.0

```
Epoch 1/15
63/63 [==============================] - 6s 65ms/step - loss: 0.6959 - accuracy: 0.5045 - val_loss: 0.6945 - val_accuracy: 0.5000
Epoch 2/15
63/63 [==============================] - 5s 77ms/step - loss: 0.6920 - accuracy: 0.5245 - val_loss: 0.6761 - val_accuracy: 0.5710
Epoch 3/15
63/63 [==============================] - 4s 61ms/step - loss: 0.6745 - accuracy: 0.5935 - val_loss: 0.6555 - val_accuracy: 0.6330
Epoch 4/15
63/63 [==============================] - 4s 62ms/step - loss: 0.6494 - accuracy: 0.6465 - val_loss: 0.6898 - val_accuracy: 0.5920
Epoch 5/15
63/63 [==============================] - 4s 61ms/step - loss: 0.6323 - accuracy: 0.6665 - val_loss: 0.6120 - val_accuracy: 0.6610
Epoch 6/15
63/63 [==============================] - 4s 61ms/step - loss: 0.5932 - accuracy: 0.6845 - val_loss: 0.6062 - val_accuracy: 0.6670
Epoch 7/15
63/63 [==============================] - 5s 78ms/step - loss: 0.5589 - accuracy: 0.7150 - val_loss: 0.5707 - val_accuracy: 0.7070
Epoch 8/15
63/63 [==============================] - 4s 59ms/step - loss: 0.5255 - accuracy: 0.7370 - val_loss: 0.6010 - val_accuracy: 0.6720
Epoch 9/15
63/63 [==============================] - 4s 60ms/step - loss: 0.4850 - accuracy: 0.7635 - val_loss: 0.5969 - val_accuracy: 0.7140
Epoch 10/15
63/63 [==============================] - 5s 77ms/step - loss: 0.4565 - accuracy: 0.7835 - val_loss: 0.5805 - val_accuracy: 0.6860
Epoch 11/15
63/63 [==============================] - 4s 61ms/step - loss: 0.4048 - accuracy: 0.8170 - val_loss: 0.7368 - val_accuracy: 0.7010
Epoch 12/15
63/63 [==============================] - 5s 76ms/step - loss: 0.3683 - accuracy: 0.8300 - val_loss: 0.5917 - val_accuracy: 0.7180
Epoch 13/15
63/63 [==============================] - 4s 62ms/step - loss: 0.3105 - accuracy: 0.8685 - val_loss: 0.8100 - val_accuracy: 0.6870
Epoch 14/15
63/63 [==============================] - 4s 63ms/step - loss: 0.2451 - accuracy: 0.9025 - val_loss: 0.9380 - val_accuracy: 0.7200
Epoch 15/15
63/63 [==============================] - 5s 76ms/step - loss: 0.2180 - accuracy: 0.9150 - val_loss: 0.8922 - val_accuracy: 0.6850
```




```
32/32 [==============================] - 1s 29ms/step - loss: 0.6089 - accuracy: 0.7000
Test accuracy: 0.700
```

Test Accuracy = 70.00 %

From the plot we can see that the optimal number of epochs =7

1 : Tuning the model using Drop-out, Augmentation and adjusting the number of Max Pooling Layers

Epochs	Batch Size	Drop-Out	Augmentation	Max pooling	Training Samples	Validation Accuracy	Test Accuracy
7	32	0.2	Horizontal= 0.05 Zoom = 0.01	1,2,3,4	1000	72.20	71.70
7	32	0.1	Horizontal= 0.05 Zoom = 0.01	2,4,6,2	1000	75.30	74.20

```
63/63 [==============================] - 18s 219ms/step - loss: 0.6964 - accuracy: 0.5125 - val_loss: 0.6887 - val_accuracy: 0.5000
Epoch 2/7
63/63 [==============================] - 14s 214ms/step - loss: 0.6866 - accuracy: 0.5460 - val_loss: 0.7274 - val_accuracy: 0.5010
Epoch 3/7
63/63 [==============================] - 13s 209ms/step - loss: 0.6586 - accuracy: 0.6180 - val_loss: 0.6217 - val_accuracy: 0.6470
Epoch 4/7
63/63 [==============================] - 14s 211ms/step - loss: 0.6171 - accuracy: 0.6675 - val_loss: 0.5890 - val_accuracy: 0.6760
Epoch 5/7
63/63 [==============================] - 14s 216ms/step - loss: 0.5767 - accuracy: 0.7020 - val_loss: 0.5655 - val_accuracy: 0.7020
Epoch 6/7
63/63 [==============================] - 15s 231ms/step - loss: 0.5309 - accuracy: 0.7510 - val_loss: 0.5254 - val_accuracy: 0.7290
Epoch 7/7
63/63 [==============================] - 14s 217ms/step - loss: 0.5139 - accuracy: 0.7465 - val_loss: 0.5086 - val_accuracy: 0.7530
```

```
32/32 [==============================] - 1s 29ms/step - loss: 0.5534 - accuracy: 0.7420
Test accuracy: 0.742
```

Test Accuracy increased to 74.20 % from 70%

2: <u>Increasing Training Sample from 1000 to 1500 and training the model</u>

Epochs	Batch Size	Drop-Out	Augmentation	Max pooling	Training Samples	Validation Accuracy	Test Accuracy
7	32	0.1	Horizontal= 0.05 Zoom = 0.01	2,4,6,2	1500	80.80	80.40

```
Epoch 1/7
94/94 [==============================] - 20s 210ms/step - loss: 0.3228 - accuracy: 0.8607 - val_loss: 0.4863 - val_accuracy: 0.7960
Epoch 2/7
94/94 [==============================] - 20s 212ms/step - loss: 0.2888 - accuracy: 0.8763 - val_loss: 0.5646 - val_accuracy: 0.7600
Epoch 3/7
94/94 [==============================] - 19s 196ms/step - loss: 0.2716 - accuracy: 0.8877 - val_loss: 0.5254 - val_accuracy: 0.7860
Epoch 4/7
94/94 [==============================] - 20s 213ms/step - loss: 0.2569 - accuracy: 0.8917 - val_loss: 0.6400 - val_accuracy: 0.7740
Epoch 5/7
94/94 [==============================] - 20s 207ms/step - loss: 0.2506 - accuracy: 0.9003 - val_loss: 0.5593 - val_accuracy: 0.8080
Epoch 6/7
94/94 [==============================] - 20s 205ms/step - loss: 0.2447 - accuracy: 0.8993 - val_loss: 0.5611 - val_accuracy: 0.7920
Epoch 7/7
94/94 [==============================] - 20s 210ms/step - loss: 0.2375 - accuracy: 0.9043 - val_loss: 0.6120 - val_accuracy: 0.7880
```

```
16/16 [==============================] - 1s 25ms/step - loss: 0.4552 - accuracy: 0.8040
Test accuracy: 0.804
```

Test Accuracy increased to 80.40 % from 74.20 %

3 : Training the model using 3000 training samples with Padding and Strides

Epochs	Batch Size	Drop-Out	Augmentation	Max pooling	Training Samples	Validation Accuracy	Test Accuracy
7	32	0.1	Horizontal= 0.05 Zoom = 0.01	2,4,6,2	3000	87.70	86.20

```
Epoch 1/7
188/188 [==============================] - 41s 220ms/step - loss: 0.1843 - accuracy: 0.9293 - val_loss: 0.3791 - val_accuracy: 0.8650
Epoch 2/7
188/188 [==============================] - 42s 223ms/step - loss: 0.1637 - accuracy: 0.9360 - val_loss: 0.4281 - val_accuracy: 0.8530
Epoch 3/7
188/188 [==============================] - 41s 218ms/step - loss: 0.1731 - accuracy: 0.9313 - val_loss: 0.3783 - val_accuracy: 0.8740
Epoch 4/7
188/188 [==============================] - 42s 218ms/step - loss: 0.1521 - accuracy: 0.9400 - val_loss: 0.4584 - val_accuracy: 0.8710
Epoch 5/7
188/188 [==============================] - 42s 222ms/step - loss: 0.1506 - accuracy: 0.9385 - val_loss: 0.3924 - val_accuracy: 0.8620
Epoch 6/7
188/188 [==============================] - 41s 215ms/step - loss: 0.1342 - accuracy: 0.9452 - val_loss: 0.4705 - val_accuracy: 0.8720
Epoch 7/7
188/188 [==============================] - 41s 217ms/step - loss: 0.1303 - accuracy: 0.9488 - val_loss: 0.4424 - val_accuracy: 0.8770

32/32 [==============================] - 1s 31ms/step - loss: 0.3904 - accuracy: 0.8620
Test accuracy: 0.862
```

Test Accuracy increased to 86.20% from 80.40%

Increasing the training sample to 4000.

Epochs	Batch Size	Drop-Out	Augmentation	Max pooling	Training Samples	Validation Accuracy	Test Accuracy
7	32	0.1	Horizontal= 0.05 Zoom = 0.01	2,4,6,2	4000	87.20	85.20

```
Epoch 1/7
250/250 [==============================] - 56s 221ms/step - loss: 0.2421 - accuracy: 0.8963 - val_loss: 0.3844 - val_accuracy: 0.8600
Epoch 2/7
250/250 [==============================] - 55s 218ms/step - loss: 0.2297 - accuracy: 0.9003 - val_loss: 0.4356 - val_accuracy: 0.8570
Epoch 3/7
250/250 [==============================] - 55s 219ms/step - loss: 0.2214 - accuracy: 0.9051 - val_loss: 0.4088 - val_accuracy: 0.8500
Epoch 4/7
250/250 [==============================] - 56s 222ms/step - loss: 0.2018 - accuracy: 0.9159 - val_loss: 0.3535 - val_accuracy: 0.8730
Epoch 5/7
250/250 [==============================] - 55s 218ms/step - loss: 0.2027 - accuracy: 0.9171 - val_loss: 0.4032 - val_accuracy: 0.8460
Epoch 6/7
250/250 [==============================] - 55s 221ms/step - loss: 0.1928 - accuracy: 0.9186 - val_loss: 0.3572 - val_accuracy: 0.8620
Epoch 7/7
250/250 [==============================] - 54s 216ms/step - loss: 0.1782 - accuracy: 0.9261 - val_loss: 0.4573 - val_accuracy: 0.8720

32/32 [==============================] - 1s 29ms/step - loss: 0.3681 - accuracy: 0.8520
Test accuracy: 0.852
```

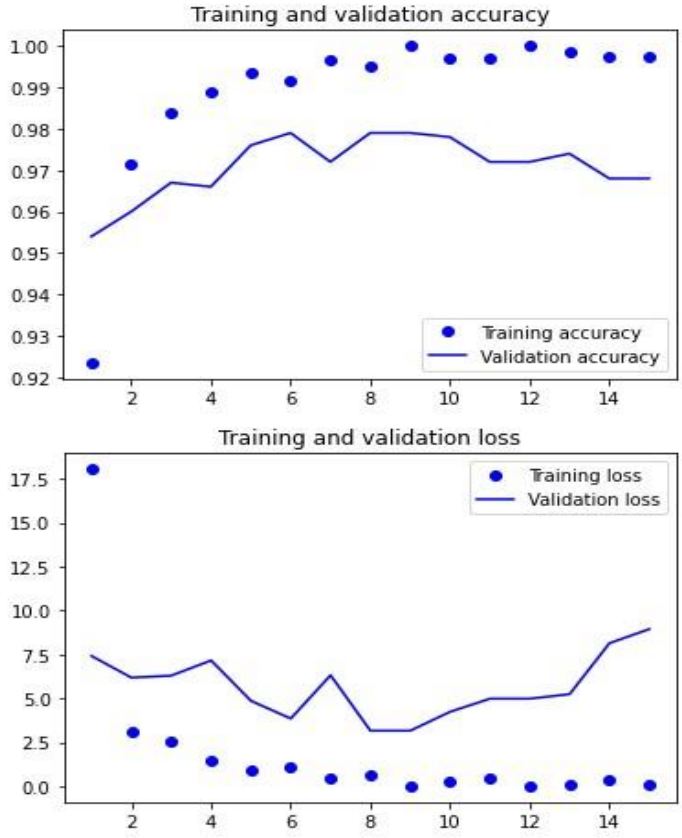
Further increase of training sample from 3000 to 4000 resulted a decrease in the test accuracy of the model. Therefore, the optimal number of training set samples would be 3000 samples.

Best Accuracy so far obtained is 86.20% when we use 3000 samples to train the model.

4: Using a pretrained network and running the model to find optimal number of epochs

Epochs	Batch Size	Drop-Out	Augmentation	Max pooling	Training Samples	Validation Accuracy	Test Accuracy
15	32	-	-	2,4,6,2	1000	97.70	97.10

```
Epoch 1/15
63/63 [==============================] - 3s 9ms/step - loss: 17.8855 - accuracy: 0.9290 - val_loss: 9.9470 - val_accuracy: 0.9470
Epoch 2/15
63/63 [==============================] - 0s 6ms/step - loss: 5.1980 - accuracy: 0.9700 - val_loss: 5.4119 - val_accuracy: 0.9600
Epoch 3/15
63/63 [==============================] - 0s 6ms/step - loss: 0.7922 - accuracy: 0.9890 - val_loss: 2.5885 - val_accuracy: 0.9770
Epoch 4/15
63/63 [==============================] - 0s 5ms/step - loss: 0.7726 - accuracy: 0.9920 - val_loss: 8.2720 - val_accuracy: 0.9610
Epoch 5/15
63/63 [==============================] - 0s 5ms/step - loss: 2.1407 - accuracy: 0.9895 - val_loss: 3.4311 - val_accuracy: 0.9770
Epoch 6/15
63/63 [==============================] - 0s 5ms/step - loss: 0.7334 - accuracy: 0.9935 - val_loss: 4.6852 - val_accuracy: 0.9750
Epoch 7/15
63/63 [==============================] - 0s 5ms/step - loss: 0.9501 - accuracy: 0.9935 - val_loss: 5.6626 - val_accuracy: 0.9680
Epoch 8/15
63/63 [==============================] - 0s 4ms/step - loss: 0.2308 - accuracy: 0.9960 - val_loss: 4.9018 - val_accuracy: 0.9750
Epoch 9/15
63/63 [==============================] - 0s 5ms/step - loss: 0.5459 - accuracy: 0.9945 - val_loss: 9.0519 - val_accuracy: 0.9580
Epoch 10/15
63/63 [==============================] - 0s 4ms/step - loss: 0.3614 - accuracy: 0.9975 - val_loss: 4.0309 - val_accuracy: 0.9780
Epoch 11/15
63/63 [==============================] - 0s 4ms/step - loss: 0.1224 - accuracy: 0.9985 - val_loss: 4.0075 - val_accuracy: 0.9770
Epoch 12/15
63/63 [==============================] - 0s 5ms/step - loss: 0.2915 - accuracy: 0.9965 - val_loss: 6.0371 - val_accuracy: 0.9710
Epoch 13/15
63/63 [==============================] - 0s 5ms/step - loss: 0.0589 - accuracy: 0.9990 - val_loss: 6.4779 - val_accuracy: 0.9720
Epoch 14/15
63/63 [==============================] - 0s 4ms/step - loss: 0.0855 - accuracy: 0.9990 - val_loss: 4.7639 - val_accuracy: 0.9730
Epoch 15/15
63/63 [==============================] - 0s 4ms/step - loss: 3.2514e-27 - accuracy: 1.0000 - val_loss: 4.7639 - val_accuracy: 0.9730
```




```
63/63 [==============================] - 1s 16ms/step - loss: 4.8000 - accuracy: 0.9710
Test accuracy: 0.971
```

From the plot we can see that the optimal number of epochs =6

4: Feature Extraction with image augmentation, drop-out on pre-trained network.

Epochs	Batch Size	Drop-Out	Augmentation	Max pooling	Training Samples	Validation Accuracy	Test Accuracy
6	32	0.5	Horizontal= 0.01 Zoom = 0.02	2,4,6,2	1000	98.10	97.20

```
Epoch 1/6
63/63 [==============================] - 7s 113ms/step - loss: 5.8891 - accuracy: 0.9575 - val_loss: 3.7089 - val_accuracy: 0.9720
Epoch 2/6
63/63 [==============================] - 7s 110ms/step - loss: 3.8952 - accuracy: 0.9705 - val_loss: 3.4797 - val_accuracy: 0.9800
Epoch 3/6
63/63 [==============================] - 7s 107ms/step - loss: 1.0862 - accuracy: 0.9905 - val_loss: 4.1510 - val_accuracy: 0.9700
Epoch 4/6
63/63 [==============================] - 7s 106ms/step - loss: 1.1194 - accuracy: 0.9910 - val_loss: 5.7490 - val_accuracy: 0.9700
Epoch 5/6
63/63 [==============================] - 7s 110ms/step - loss: 0.8732 - accuracy: 0.9915 - val_loss: 3.2642 - val_accuracy: 0.9790
Epoch 6/6
63/63 [==============================] - 7s 107ms/step - loss: 1.7374 - accuracy: 0.9890 - val_loss: 5.9580 - val_accuracy: 0.9750


63/63 [==============================] - 1s 16ms/step - loss: 5.0877 - accuracy: 0.9720
Test accuracy: 0.972
```

Test Accuracy increased from 97.10 to 97.20.

2: Increasing sample size from 1000 to 1500

Epochs	Batch Size	Drop-Out	Augmentation	Max pooling	Training Samples	Validation Accuracy	Test Accuracy
6	32	0.5	Horizontal= 0.01 Zoom = 0.02	2,4,6,2	1500	98.40	98.00

```
Epoch 1/6
94/94 [==============================] - 10s 104ms/step - loss: 0.8693 - accuracy: 0.9947 - val_loss: 7.5665 - val_accuracy: 0.9740
Epoch 2/6
94/94 [==============================] - 10s 104ms/step - loss: 0.9980 - accuracy: 0.9913 - val_loss: 6.8725 - val_accuracy: 0.9740
Epoch 3/6
94/94 [==============================] - 10s 104ms/step - loss: 0.2297 - accuracy: 0.9983 - val_loss: 5.5052 - val_accuracy: 0.9840
Epoch 4/6
94/94 [==============================] - 10s 103ms/step - loss: 0.4306 - accuracy: 0.9953 - val_loss: 6.7589 - val_accuracy: 0.9780
Epoch 5/6
94/94 [==============================] - 10s 103ms/step - loss: 0.6950 - accuracy: 0.9943 - val_loss: 6.0469 - val_accuracy: 0.9740
Epoch 6/6
94/94 [==============================] - 10s 101ms/step - loss: 0.4385 - accuracy: 0.9963 - val_loss: 7.5356 - val_accuracy: 0.9760


16/16 [==============================] - 1s 17ms/step - loss: 2.6528 - accuracy: 0.9800
Test accuracy: 0.980
```

Test Accuracy increased to 98.00% from 97.20%

3: Increasing training sample to 2000 and freezing layers with hyper parameter tuning using learning rate

Epochs	Batch Size	Drop-Out	Augmentation	Learning Rate	Training Samples	Validation Accuracy	Test Accuracy
6	32	0.1	Horizontal= 0.01 Zoom = 0.02	0.00001	1750	98.60	98.60

```
110/110 [==============================] - 15s 106ms/step - loss: 12.0791 - accuracy: 0.9363 - val_loss: 1.8708 - val_accuracy: 0.9860
Epoch 2/6
110/110 [==============================] - 11s 102ms/step - loss: 2.1700 - accuracy: 0.9789 - val_loss: 3.0049 - val_accuracy: 0.9840
Epoch 3/6
110/110 [==============================] - 11s 103ms/step - loss: 1.4318 - accuracy: 0.9871 - val_loss: 1.8526 - val_accuracy: 0.9860
Epoch 4/6
110/110 [==============================] - 11s 102ms/step - loss: 1.1390 - accuracy: 0.9863 - val_loss: 4.5096 - val_accuracy: 0.9780
Epoch 5/6
110/110 [==============================] - 11s 102ms/step - loss: 0.7619 - accuracy: 0.9917 - val_loss: 2.7488 - val_accuracy: 0.9840
Epoch 6/6
110/110 [==============================] - 11s 102ms/step - loss: 0.2109 - accuracy: 0.9963 - val_loss: 2.5792 - val_accuracy: 0.9840

16/16 [==============================] - 1s 17ms/step - loss: 1.9621 - accuracy: 0.9860
Test accuracy: 0.986
```

Test Accuracy increased to 98.60% from 98 %

Increasing training sample to 2000 and freezing layers with hyper parameter tuning using learning rate.

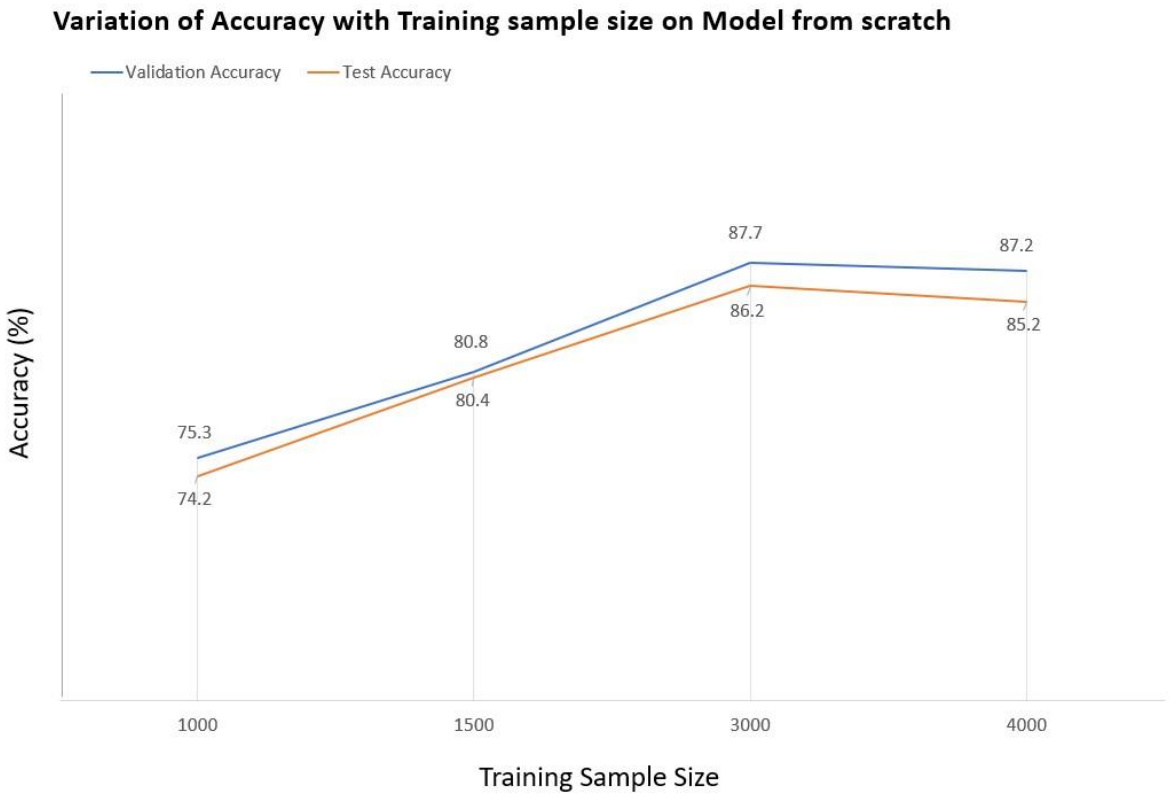
Epochs	Batch Size	Drop-Out	Augmentation	Learning Rate	Training Samples	Validation Accuracy	Test Accuracy
6	32	0.1	Horizontal= 0.01 Zoom = 0.02	0.00001	2000	96.20	95.60

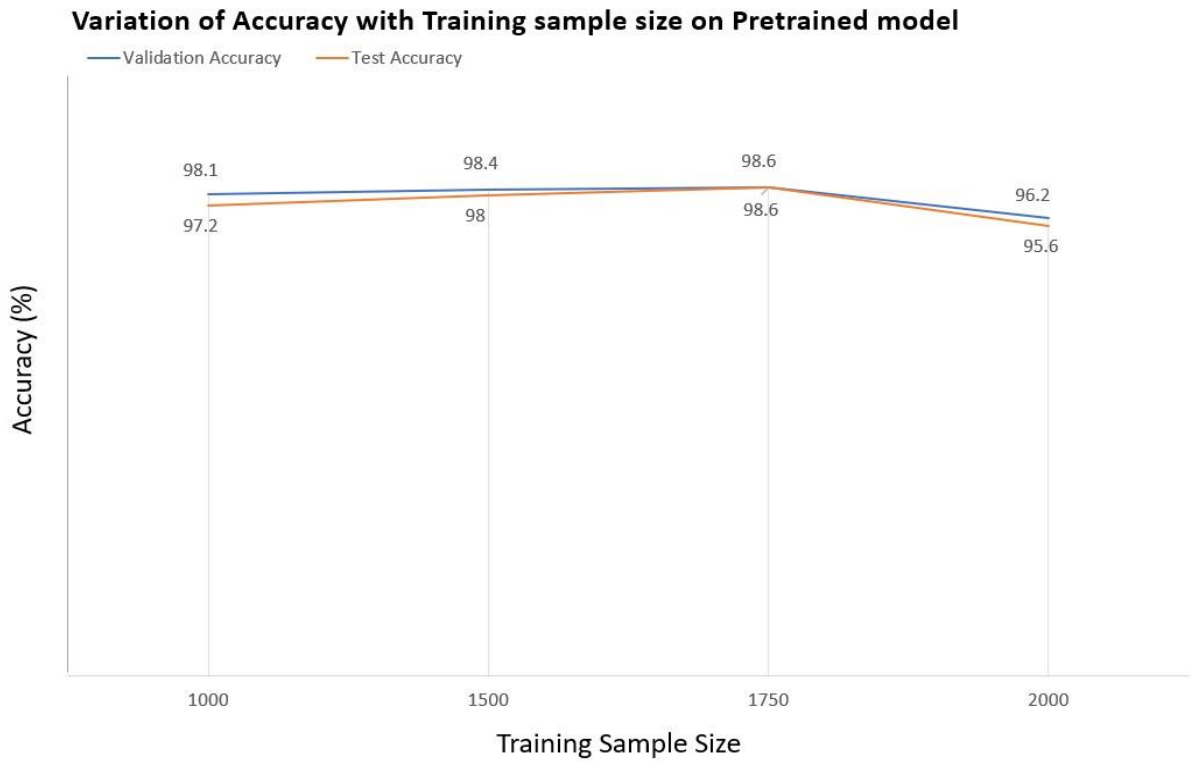
```
157/157 [==============================] - 20s 103ms/step - loss: 2.3987 - accuracy: 0.9882 - val_loss: 7.2690 - val_accuracy: 0.9580
Epoch 2/6
157/157 [==============================] - 16s 100ms/step - loss: 2.2742 - accuracy: 0.9872 - val_loss: 7.3012 - val_accuracy: 0.9600
Epoch 3/6
157/157 [==============================] - 16s 100ms/step - loss: 2.0024 - accuracy: 0.9886 - val_loss: 7.2703 - val_accuracy: 0.9600
Epoch 4/6
157/157 [==============================] - 16s 101ms/step - loss: 2.0066 - accuracy: 0.9878 - val_loss: 7.2840 - val_accuracy: 0.9600
Epoch 5/6
157/157 [==============================] - 16s 102ms/step - loss: 2.2211 - accuracy: 0.9886 - val_loss: 7.2210 - val_accuracy: 0.9600
Epoch 6/6
157/157 [==============================] - 16s 101ms/step - loss: 1.8825 - accuracy: 0.9882 - val_loss: 7.2290 - val_accuracy: 0.9620

32/32 [==============================] - 1s 16ms/step - loss: 5.5635 - accuracy: 0.9560
Test accuracy: 0.956
```

Test Accuracy decreased from 98.60% to 95.60% when training samples are increased to 2000.

Best Accuracy so far obtained is 98.60 % when we use a training sample of size 1750.

Results and Findings





SUMMARY

- As we can see from the above results the choice of the network model and the training sample size has high inter-dependability.

- As the training sample is increased, we can see a significant increase in the accuracy of the model on the test set. If we continue increasing the training sample size after a particular point, the accuracy decreases due to over fitting of the model.

- The sweet spot where the model gives the best accuracy without underfitting or overfitting can be defined as the optimal training sample size for the model.

- The network model can be chosen based upon the classification problem and the amount of training data available.

- The second model we are using is a pre-trained model with VGG16 network architecture. These pre-trained models are capable of capturing the complex features and can save training time of the model as they are already trained.

- The pre-trained weights of the VGG16 model can be applied to transfer learning on other image classification problems with smaller datasets because they were pre-trained on a significantly large dataset with over a million images.

- Due to the pre-trained model's prior learning of useful features that can be applied to the new task, this transfer learning strategy can save training time and enhance performance.

- As we can see from the above experiment the pre-trained model was able to come up with 98.60% accuracy with relatively smaller training samples where the model that we build from scratch required 3000 training samples to come up with an accuracy of 86.20%