

Abstract:

Optical character recognition (OCR) is a procedure of translating and retrieving information from images of typed and handwritten text into a format which is machine recognisable and editable. For this project we have implemented two models for character recognition: InceptionV3 and VGG-16. Both the models are preprocessed using 5000 images and 26 classes from the NIST Special Database 19 Dataset. These models were trained in 50 epoches and their results are compared with changed parameters.

Introduction:

We were really intrigued by how the neural networks work towards classifying images as we saw a glimpse of it in Week 3 of the class and the second homework of this course (Intro to Computer Vision). We went through a couple of papers where samples of handwritten characters were taken through different sources and then used for character recognition in scanned documents. Though we did not implement that, we built two CNN architectures without using the inbuilt architecture in python. The two models implemented are VGG-16 and InceptionV3. We experimented with these architectures and trained hyperparameters to obtain different results which we then compared.

Related Work:

Optical Character Recognition using Convolutional Neural Network-

Optical Character Recognition (OCR) is a method of converting printed or handwritten text into a machine-readable format. The most common applications of OCR are editing, searching, and memory reduction. The text image is sent into a segmentation algorithm in this paper, which splits the image into lines, words, and characters. After that, a Convolutional Neural Network is used to recognize the characters that have been obtained. In comparison to machine learning models like Support Vector Machines and Artificial Neural Networks, it produces greater outcomes.

Improved Optical Character Recognition with Deep Neural Network-

Optical Character Recognition (OCR) is a powerful tool for extracting information from pixel-based images and converting it into machine-editable forms. Broken and fuzzy text pictures from printed documents make it harder to recognize and convert. They used the InceptionV3 model to train and conduct the OCR in this paper. It's been given 53,342 character images from newspapers to train with. In comparison to conventional OCRs, they achieved greater accuracy on low-quality text images, resulting in a 21.5 percent drop in error rate.

CNN based Optical Character Recognition and Applications

The process of converting handwritten or typewritten text into a computer-readable format is known as optical character recognition. It is mostly used for editing, indexing, and storage space reduction. The entire operation entails character-by-character scanning of text images, preprocessing, and conversion to the ASCII value of each character in the image. Pre-processing, character recognition, character segmentation, and data presentation are all handled by the Optical Character Recognition system. They used the VGG16 CNN model to train a Telugu character dataset of 1600 characters and calculated its accuracy in this study.

Contribution/Method:

Originally the dataset that we considered for the project was 1/8th times the NIST special dataset 19 which originally had all the uppercase letters and numbers and a few lowercase letters. The number of classes was 47. We initially planned to train our model with 100,000 images which were uniformly picked from different classes and then split into train and test in the ratio 4:1. Though this worked, it took too long for us to complete the project in time. We also tried reducing the data to 50,000 but training would use up the GPU on the multiple google account. Also, once the GPU is used up it would slow up the process of training even more.

InceptionV3:

Building the architecture:

1. Factorize into smaller convolutions: This is to keep a check on network efficiency as it reduces the number of parameters which reduces computational efficiency. The bigger convolutions like 5X5 are replaced by 2 smaller 3X3 convolutions. (Inception Block A)

$$5 \times 5 = 25$$

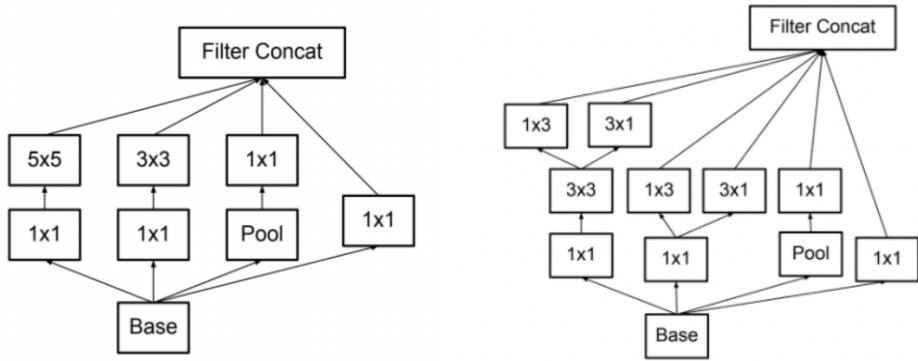
$$3 \times 3 + 3 \times 3 = 18$$

This reduces the number of parameters by

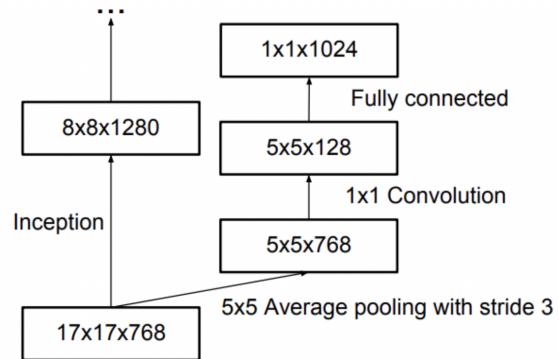
2. Factorizing into Asymmetric convolutions: A 3x3 convolution can be replaced by 2 asymmetric ones. (Inception block B and C)

$$3 \times 3 = 9$$

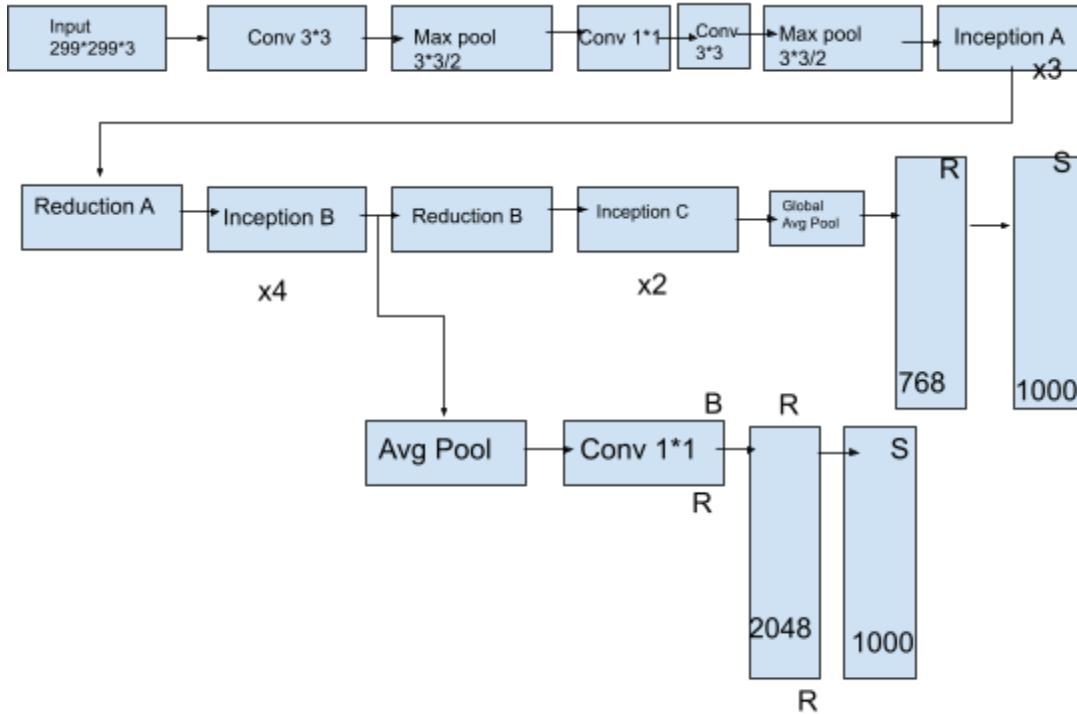
$$1 \times 3 + 3 \times 1 = 6$$



3. Auxiliary classifier: In InceptionV3 an auxiliary classifier takes the role of a regularizer as it is a small CNN that is inserted in between layers. This is done during training and the loss is taken and added to the network loss.



InceptionV3 Model Architecture (Block diagram)-



```

In [1]: Found 40820 images belonging to 47 classes.
Found 10228 images belonging to 47 classes.
{'2': 0, '3': 1, '4': 2, '5': 3, '6': 4, '7': 5, '8': 6, '9': 7, 'A': 8, 'B': 9, 'C': 10, 'D': 11, 'E': 12, 'F': 13, 'G': 14, 'H': 15, 'I': 16, 'J': 17, 'K': 18}
Model: "model"
Layer (type)      Output Shape         Param #     Connected to
=====
input_1 (InputLayer) [(None, 299, 299, 3  0   )]        []
conv2d (Conv2D)    (None, 149, 149, 32  864  )        ['input_1[0][0]']
batch_normalization (BatchNorm  alization) (None, 149, 149, 32  96  )        ['conv2d[0][0]']

```

```

None
Model Loaded!!
/usr/local/lib/python3.7/dist-packages/ipykernel_launcher.py:81: UserWarning: `Model.fit_generator` is deprecated and will be removed in a future version. Please use `Model.fit`.
Epoch 1/50
1276/1276 [=====] - 2142s 2s/step - loss: 1.2416 - val_loss: 1.1154
Epoch 2/50
657/1276 [=====>.....] - ETA: 16:00 - loss: 0.7409

```

```

Total params: 21,899,087
Trainable params: 21,864,655
Non-trainable params: 34,432
None
Model Loaded!!
/usr/local/lib/python3.7/dist-packages/ipykernel_launcher.py:81: UserWarning: `Model.fit_generator` is deprecated and will be removed in a future version. Please use `Model.fit`.
Epoch 1/10
2127/2552 [=====>.....] - ETA: 44:36 - loss: 1.3869

```

The data with 50,000 images with different batch sizes

```

=====
Total params: 21,899,087
Trainable params: 21,864,655
Non-trainable params: 34,432

None
Model Loaded!!
/usr/local/lib/python3.7/dist-packages/ipykernel_launcher.py:95: UserWarning: `Model.fit_generator` is deprecated and will be removed in a future version. Pl
Epoch 1/5
227/638 [=====>.....] - ETA: 4:27:50 - loss: 0.4147 - accuracy: 0.8534

```

For our actual results we used a dataset of 5000 which we split into training and testing in the ratio 8:2 we also removed the classes with alphabets and lowercase letters. This left us with 26 classes.

INCEPTIONV3

```

predictions (Dense)      (None, 47)      96303      ['avg_pool[0][0]']

=====
Total params: 21,899,087
Trainable params: 21,864,655
Non-trainable params: 34,432

None
Model Loaded!!
/usr/local/lib/python3.7/dist-packages/ipykernel_launcher.py:90: UserWarning: `Model.fit_generator` is deprecated and will be re
Epoch 1/10
545/638 [=====>.....] - ETA: 17:56 - loss: 1.7011

Total params: 21,899,087
Clear output      ms: 21,864,655
                  params: 34,432
executed at unknown time
None
Model Loaded!!
/usr/local/lib/python3.7/dist-packages/ipykernel_launcher.py:90: UserWarning: `Model.fit_generator` is deprecated and will be re
Epoch 1/10
638/638 [=====] - 9074s 14s/step - loss: 1.6037 - val_loss: 1.6373
Epoch 2/10
638/638 [=====] - 998s 2s/step - loss: 0.8818 - val_loss: 1.6756
Epoch 3/10
638/638 [=====] - 993s 2s/step - loss: 0.7373 - val_loss: 0.9779
Epoch 4/10
638/638 [=====] - 993s 2s/step - loss: 0.6671 - val_loss: 0.6106
Epoch 5/10
434/638 [=====>.....] - ETA: 5:03 - loss: 0.6239

```

VGG16

```

Total params: 134,330,138
Trainable params: 134,330,138
Non-trainable params: 0

None
Epoch 1/20
62/63 [=====>..] - ETA: 37s - loss: 3.2554 Epoch 1/20
63/63 [=====] - 3143s 50s/step - loss: 3.2553 - val_loss: 3.2526
Epoch 2/20
62/63 [=====>..] - ETA: 0s - loss: 3.2501 Epoch 1/20
63/63 [=====] - 52s 829ms/step - loss: 3.2500 - val_loss: 3.2476
Epoch 3/20
62/63 [=====>..] - ETA: 0s - loss: 3.2453 Epoch 1/20
63/63 [=====] - 52s 825ms/step - loss: 3.2452 - val_loss: 3.2428

```

Performance Metrics:

SGD Learning rate - 0.001

F 28	Accuracy: 0.8235294117647058 Precision: 0.8235294117647058 Recall: 1.0 F1-Score: 0.9032258064516129
G 9	Accuracy: 0.9 Precision: 0.9 Recall: 1.0 F1-Score: 0.9473684210526316
T 35	Accuracy: 0.9722222222222222 Precision: 0.9722222222222222 Recall: 1.0 F1-Score: 0.9859154929577464
N 27	Accuracy: 0.8709677419354839 Precision: 0.8709677419354839 Recall: 1.0 F1-Score: 0.9310344827586207
R 15	Accuracy: 0.7894736842105263 Precision: 0.7894736842105263 Recall: 1.0 F1-Score: 0.8823529411764706
I 130	Accuracy: 0.9285714285714286 Precision: 0.9285714285714286 Recall: 1.0 F1-Score: 0.962962962962963
U 48	Accuracy: 0.8421052631578947 Precision: 0.8421052631578947 Recall: 1.0 F1-Score: 0.9142857142857143
Z 0	Accuracy: 0.0
S 83	Accuracy: 0.9651162790697675 Precision: 0.9651162790697675 Recall: 1.0 F1-Score: 0.9822485207100593
A 17	Accuracy: 0.7083333333333334 Precision: 0.7083333333333334 Recall: 1.0 F1-Score: 0.8292682926829268
O 125	Accuracy: 0.984251968503937 Precision: 0.984251968503937 Recall: 1.0 F1-Score: 0.9920634920634921
H 10	Accuracy: 0.8333333333333334 Precision: 0.8333333333333334 Recall: 1.0 F1-Score: 0.9090909090909091
M 42	Accuracy: 0.9767441860465116 Precision: 0.9767441860465116 Recall: 1.0 F1-Score: 0.988235294117647
X 19	Accuracy: 0.9047619047619048 Precision: 0.9047619047619048 Recall: 1.0 F1-Score: 0.9500000000000001
C 42	Accuracy: 0.875 Precision: 0.875 Recall: 1.0 F1-Score: 0.9333333333333333
E 16	Accuracy: 0.8421052631578947 Precision: 0.8421052631578947 Recall: 1.0 F1-Score: 0.9142857142857143
B 13	Accuracy: 0.8666666666666667 Precision: 0.8666666666666667 Recall: 1.0 F1-Score: 0.9285714285714286
V 24	Accuracy: 0.8571428571428571 Precision: 0.8571428571428571 Recall: 1.0 F1-Score: 0.923076923076923
D 11	Accuracy: 0.6470588235294118 Precision: 0.6470588235294118 Recall: 1.0 F1-Score: 0.7857142857142858
K 17	Accuracy: 0.8947368421052632 Precision: 0.8947368421052632 Recall: 1.0 F1-Score: 0.9444444444444444
Q 9	Accuracy: 0.9 Precision: 0.9 Recall: 1.0 F1-Score: 0.9473684210526316
J 18	Accuracy: 0.8571428571428571 Precision: 0.8571428571428571 Recall: 1.0 F1-Score: 0.923076923076923
L 24	Accuracy: 0.32 Precision: 0.32 Recall: 1.0 F1-Score: 0.4848484848484848
Y 24	Accuracy: 0.8888888888888888 Precision: 0.8888888888888888 Recall: 1.0 F1-Score: 0.9411764705882353
P 36	Accuracy: 0.9 Precision: 0.9 Recall: 1.0 F1-Score: 0.9473684210526316
W 24	Accuracy: 0.8571428571428571 Precision: 0.8571428571428571 Recall: 1.0 F1-Score: 0.923076923076923

SGD Learning rate - 0.01

F 30
Accuracy: 0.8823529411764706 Precision: 0.8823529411764706 Recall: 1.0 F1-Score: 0.9375
G 6
Accuracy: 0.6 Precision: 0.6 Recall: 1.0 F1-Score: 0.7499999999999999
T 35
Accuracy: 0.9722222222222222 Precision: 0.9722222222222222 Recall: 1.0 F1-Score: 0.9859154929577464
N 22
Accuracy: 0.7096774193548387 Precision: 0.7096774193548387 Recall: 1.0 F1-Score: 0.8301886792452831
R 15
Accuracy: 0.7894736842105263 Precision: 0.7894736842105263 Recall: 1.0 F1-Score: 0.8823529411764706
I 134
Accuracy: 0.9571428571428572 Precision: 0.9571428571428572 Recall: 1.0 F1-Score: 0.9781021897810218
U 49
Accuracy: 0.8596491228070176 Precision: 0.8596491228070176 Recall: 1.0 F1-Score: 0.9245283018867925
Z 0
Accuracy: 0.0
S 78
Accuracy: 0.9069767441860465 Precision: 0.9069767441860465 Recall: 1.0 F1-Score: 0.951219512195122
A 22
Accuracy: 0.9166666666666666 Precision: 0.9166666666666666 Recall: 1.0 F1-Score: 0.9565217391304348
O 115
Accuracy: 0.905511811023622 Precision: 0.905511811023622 Recall: 1.0 F1-Score: 0.9504132231404958
H 11
Accuracy: 0.9166666666666666 Precision: 0.9166666666666666 Recall: 1.0 F1-Score: 0.9565217391304348
M 40
Accuracy: 0.9302325581395349 Precision: 0.9302325581395349 Recall: 1.0 F1-Score: 0.963855421686747
X 19
Accuracy: 0.9047619047619048 Precision: 0.9047619047619048 Recall: 1.0 F1-Score: 0.9500000000000001
C 38
Accuracy: 0.7916666666666666 Precision: 0.7916666666666666 Recall: 1.0 F1-Score: 0.8837209302325582
E 12
Accuracy: 0.631578947368421 Precision: 0.631578947368421 Recall: 1.0 F1-Score: 0.7741935483870968
B 15
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
V 20
Accuracy: 0.7142857142857143 Precision: 0.7142857142857143 Recall: 1.0 F1-Score: 0.8333333333333333
D 8
Accuracy: 0.47058823529411764 Precision: 0.47058823529411764 Recall: 1.0 F1-Score: 0.6399999999999999
K 17
Accuracy: 0.8947368421052632 Precision: 0.8947368421052632 Recall: 1.0 F1-Score: 0.9444444444444444
Q 10
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
J 18
Accuracy: 0.8571428571428571 Precision: 0.8571428571428571 Recall: 1.0 F1-Score: 0.923076923076923
L 19
Accuracy: 0.2533333333333335 Precision: 0.2533333333333335 Recall: 1.0 F1-Score: 0.4042553191489362
Y 21
Accuracy: 0.7777777777777778 Precision: 0.7777777777777778 Recall: 1.0 F1-Score: 0.8750000000000001
P 35
Accuracy: 0.875 Precision: 0.875 Recall: 1.0 F1-Score: 0.9333333333333333
W 24
Accuracy: 0.8571428571428571 Precision: 0.8571428571428571 Recall: 1.0 F1-Score: 0.923076923076923

SGD Learning rate - 0.1

F 28
Accuracy: 0.8235294117647058 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
G 5
Accuracy: 0.5 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
T 34
Accuracy: 0.9444444444444444 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
N 2
Accuracy: 0.06451612903225806 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
R 8
Accuracy: 0.42105263157894735 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
I 133
Accuracy: 0.95 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
U 39
Accuracy: 0.6842105263157895 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
Z 0
Accuracy: 0.0
S 82
Accuracy: 0.9534883720930233 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
A 0
Accuracy: 0.0
O 121
Accuracy: 0.952755905511811 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
H 10
Accuracy: 0.8333333333333334 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
M 38
Accuracy: 0.8837209302325582 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
X 18
Accuracy: 0.8571428571428571 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
C 16
Accuracy: 0.3333333333333333 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
E 16
Accuracy: 0.8421052631578947 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
P 15

B 15
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
V 16
Accuracy: 0.5714285714285714 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
D 10
Accuracy: 0.5882352941176471 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
K 18
Accuracy: 0.9473684210526315 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
Q 10
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
J 16
Accuracy: 0.7619047619047619 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
L 12
Accuracy: 0.16 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
Y 24
Accuracy: 0.8888888888888888 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
P 27
Accuracy: 0.675 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
W 28
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0

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U 43
Accuracy: 0.7543859649122807 Precision: 0.7543859649122807 Recall: 1.0 F1-Score: 0.86
G 8
Accuracy: 0.8 Precision: 0.8 Recall: 1.0 F1-Score: 0.88888888888889
Z 15
Accuracy: 0.75 Precision: 0.75 Recall: 1.0 F1-Score: 0.8571428571428571
A 23
Accuracy: 0.9583333333333334 Precision: 0.9583333333333334 Recall: 1.0 F1-Score: 0.9787234042553191
T 32
Accuracy: 0.8888888888888888 Precision: 0.8888888888888888 Recall: 1.0 F1-Score: 0.9411764705882353
N 22
Accuracy: 0.7096774193548387 Precision: 0.7096774193548387 Recall: 1.0 F1-Score: 0.8301886792452831
R 19
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
S 70
Accuracy: 0.813953488372093 Precision: 0.813953488372093 Recall: 1.0 F1-Score: 0.8974358974358974
I 18
Accuracy: 0.12857142857142856 Precision: 0.12857142857142856 Recall: 1.0 F1-Score: 0.22784810126582278
F 31
Accuracy: 0.9117647058823529 Precision: 0.9117647058823529 Recall: 1.0 F1-Score: 0.9538461538461539
O 47
Accuracy: 0.3700787401574803 Precision: 0.3700787401574803 Recall: 1.0 F1-Score: 0.5402298850574713
C 39
Accuracy: 0.8125 Precision: 0.8125 Recall: 1.0 F1-Score: 0.896551724137931
Q 9
Accuracy: 0.9 Precision: 0.9 Recall: 1.0 F1-Score: 0.9473684210526316
D 12
Accuracy: 0.7058823529411765 Precision: 0.7058823529411765 Recall: 1.0 F1-Score: 0.8275862068965517
V 24
Accuracy: 0.8571428571428571 Precision: 0.8571428571428571 Recall: 1.0 F1-Score: 0.923076923076923
M 38
Accuracy: 0.8837209302325582 Precision: 0.8837209302325582 Recall: 1.0 F1-Score: 0.9382716049382717

Accuracy: 0.8837209302325582 Precision: 0.8837209302325582 Recall: 1.0 F1-Score: 0.9382716049382717
X 11
Accuracy: 0.5238095238095238 Precision: 0.5238095238095238 Recall: 1.0 F1-Score: 0.6875000000000001
H 7
Accuracy: 0.5833333333333334 Precision: 0.5833333333333334 Recall: 1.0 F1-Score: 0.7368421052631579
J 16
Accuracy: 0.7619047619047619 Precision: 0.7619047619047619 Recall: 1.0 F1-Score: 0.8648648648648648
E 18
Accuracy: 0.9473684210526315 Precision: 0.9473684210526315 Recall: 1.0 F1-Score: 0.972972972972973
B 13
Accuracy: 0.8666666666666667 Precision: 0.8666666666666667 Recall: 1.0 F1-Score: 0.9285714285714286
K 17
Accuracy: 0.8947368421052632 Precision: 0.8947368421052632 Recall: 1.0 F1-Score: 0.9444444444444444
W 18
Accuracy: 0.6428571428571429 Precision: 0.6428571428571429 Recall: 1.0 F1-Score: 0.782608695652174
Y 23
Accuracy: 0.8518518518518519 Precision: 0.8518518518518519 Recall: 1.0 F1-Score: 0.92
L 24
Accuracy: 0.32 Precision: 0.32 Recall: 1.0 F1-Score: 0.48484848484848486
P 35
Accuracy: 0.875 Precision: 0.875 Recall: 1.0 F1-Score: 0.9333333333333333

```

Adam Learning rate - 0.01

U 55
Accuracy: 0.9649122807017544 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
G 10
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
Z 18
Accuracy: 0.9 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
A 24
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
T 34
Accuracy: 0.9444444444444444 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
N 20
Accuracy: 0.6451612903225806 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
R 18
Accuracy: 0.9473684210526315 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
S 72
Accuracy: 0.8372093023255814 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
I 6
Accuracy: 0.04285714285714286 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
F 30
Accuracy: 0.8823529411764706 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
O 10
Accuracy: 0.07874015748031496 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
C 41
Accuracy: 0.8541666666666666 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
Q 10
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
D 9
Accuracy: 0.5294117647058824 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
V 26
Accuracy: 0.9285714285714286 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
M 43
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0

X 17
Accuracy: 0.8095238095238095 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
H 12
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
J 18
Accuracy: 0.8571428571428571 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
E 16
Accuracy: 0.8421052631578947 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
B 13
Accuracy: 0.8666666666666667 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
K 16
Accuracy: 0.8421052631578947 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
W 18
Accuracy: 0.6428571428571429 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
Y 25
Accuracy: 0.9259259259259259 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
L 22
Accuracy: 0.2933333333333333 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
P 38
Accuracy: 0.95 Precision: 1.0 Recall: 1.0 F1-Score: 1.0

Adam Learning rate - 0.1

```
F 20
Accuracy: 0.5882352941176471 Precision: 0.5882352941176471 Recall: 1.0 F1-Score: 0.7407407407407407
G 9
Accuracy: 0.9 Precision: 0.9 Recall: 1.0 F1-Score: 0.9473684210526316
T 19
Accuracy: 0.5277777777777778 Precision: 0.5277777777777778 Recall: 1.0 F1-Score: 0.6909090909090909
N 25
Accuracy: 0.8064516129032258 Precision: 0.8064516129032258 Recall: 1.0 F1-Score: 0.8928571428571428
R 18
Accuracy: 0.9473684210526315 Precision: 0.9473684210526315 Recall: 1.0 F1-Score: 0.972972972972973
I 2
Accuracy: 0.014285714285714285 Precision: 0.014285714285714285 Recall: 1.0 F1-Score: 0.028169014084507043
U 45
Accuracy: 0.7894736842105263 Precision: 0.7894736842105263 Recall: 1.0 F1-Score: 0.8823529411764706
Z 7
Accuracy: 0.35 Precision: 0.35 Recall: 1.0 F1-Score: 0.5185185185185185
S 73
Accuracy: 0.8488372093023255 Precision: 0.8488372093023255 Recall: 1.0 F1-Score: 0.9182389937106918
A 18
Accuracy: 0.75 Precision: 0.75 Recall: 1.0 F1-Score: 0.8571428571428571
O 20
Accuracy: 0.15748031496062992 Precision: 0.15748031496062992 Recall: 1.0 F1-Score: 0.272108843537415
H 12
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
M 43
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
X 16
Accuracy: 0.7619047619047619 Precision: 0.7619047619047619 Recall: 1.0 F1-Score: 0.8648648648648648
C 36
Accuracy: 0.75 Precision: 0.75 Recall: 1.0 F1-Score: 0.8571428571428571
E 18
Accuracy: 0.9473684210526315 Precision: 0.9473684210526315 Recall: 1.0 F1-Score: 0.972972972972973
```

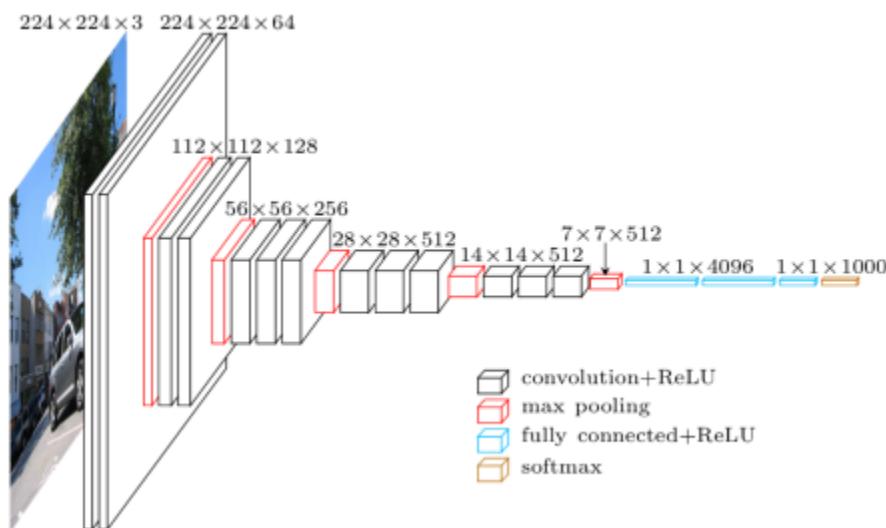
```
B 9
Accuracy: 0.6 Precision: 0.6 Recall: 1.0 F1-Score: 0.7499999999999999
V 24
Accuracy: 0.8571428571428571 Precision: 0.8571428571428571 Recall: 1.0 F1-Score: 0.923076923076923
D 10
Accuracy: 0.5882352941176471 Precision: 0.5882352941176471 Recall: 1.0 F1-Score: 0.7407407407407407
K 18
Accuracy: 0.9473684210526315 Precision: 0.9473684210526315 Recall: 1.0 F1-Score: 0.972972972972973
Q 9
Accuracy: 0.9 Precision: 0.9 Recall: 1.0 F1-Score: 0.9473684210526316
J 16
Accuracy: 0.7619047619047619 Precision: 0.7619047619047619 Recall: 1.0 F1-Score: 0.8648648648648648
L 19
Accuracy: 0.2533333333333335 Precision: 0.2533333333333335 Recall: 1.0 F1-Score: 0.4042553191489362
Y 23
Accuracy: 0.8518518518518519 Precision: 0.8518518518518519 Recall: 1.0 F1-Score: 0.92
P 38
Accuracy: 0.95 Precision: 0.95 Recall: 1.0 F1-Score: 0.9743589743589743
W 24
Accuracy: 0.8571428571428571 Precision: 0.8571428571428571 Recall: 1.0 F1-Score: 0.923076923076923
```

```

I 99
Accuracy: 0.7071428571428572 Precision: 0.7071428571428572 Recall: 1.0 F1-Score: 0.8284518828451882
G 7
Accuracy: 0.7 Precision: 0.7 Recall: 1.0 F1-Score: 0.8235294117647058
A 22
Accuracy: 0.9166666666666666 Precision: 0.9166666666666666 Recall: 1.0 F1-Score: 0.9565217391304348
F 31
Accuracy: 0.9117647058823529 Precision: 0.9117647058823529 Recall: 1.0 F1-Score: 0.9538461538461539
R 14
Accuracy: 0.7368421052631579 Precision: 0.7368421052631579 Recall: 1.0 F1-Score: 0.8484848484848484
Z 16
Accuracy: 0.8 Precision: 0.8 Recall: 1.0 F1-Score: 0.8888888888888889
T 36
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
U 50
Accuracy: 0.8771929824561403 Precision: 0.8771929824561403 Recall: 1.0 F1-Score: 0.9345794392523363
N 29
Accuracy: 0.9354838709677419 Precision: 0.9354838709677419 Recall: 1.0 F1-Score: 0.9666666666666666
S 80
Accuracy: 0.9302325581395349 Precision: 0.9302325581395349 Recall: 1.0 F1-Score: 0.963855421686747
O 124
Accuracy: 0.9763779527559056 Precision: 0.9763779527559056 Recall: 1.0 F1-Score: 0.9880478087649402
M 40
Accuracy: 0.9302325581395349 Precision: 0.9302325581395349 Recall: 1.0 F1-Score: 0.963855421686747
B 13
Accuracy: 0.8666666666666667 Precision: 0.8666666666666667 Recall: 1.0 F1-Score: 0.9285714285714286
V 26
Accuracy: 0.9285714285714286 Precision: 0.9285714285714286 Recall: 1.0 F1-Score: 0.962962962962963
X 13
Accuracy: 0.6190476190476191 Precision: 0.6190476190476191 Recall: 1.0 F1-Score: 0.7647058823529412
D 11
Accuracy: 0.6470588235294118 Precision: 0.6470588235294118 Recall: 1.0 F1-Score: 0.7857142857142858

```

VGG16:



The VGG16 model consists of 16 layers which contains

- 2 convolutional layers of filter size 64, 3x3 kernel and same padding.
- 1 max pooling layer with pool size of 2x2 and stride = 2
- 2 convolutional layers of filter size 128, 3x3 kernel and same padding.
- 1 max pooling layer with pool size of 2x2 and stride = 2
- 3 convolutional layers of filter size 256, 3x3 kernel and same padding.
- 1 max pooling layer with pool size of 2x2 and stride = 2
- 3 convolutional layers of filter size 512, 3x3 kernel and same padding.
- 1 max pooling layer with pool size of 2x2 and stride = 2
- 1 dense layer of 4096 units
- 1 dense layer of 4096 units

The RELU activation layer is added after every set of convolutional and max pooling layer.

SGD 0.001 Performance Metrics

```
I 99
Accuracy: 0.7071428571428572 Precision: 0.7071428571428572 Recall: 1.0 F1-Score: 0.8284518828451882
G 7
Accuracy: 0.7 Precision: 0.7 Recall: 1.0 F1-Score: 0.8235294117647058
A 22
Accuracy: 0.9166666666666666 Precision: 0.9166666666666666 Recall: 1.0 F1-Score: 0.9565217391304348
F 31
Accuracy: 0.9117647058823529 Precision: 0.9117647058823529 Recall: 1.0 F1-Score: 0.9538461538461539
R 14
Accuracy: 0.7368421052631579 Precision: 0.7368421052631579 Recall: 1.0 F1-Score: 0.8484848484848484
Z 16
Accuracy: 0.8 Precision: 0.8 Recall: 1.0 F1-Score: 0.8888888888888889
T 36
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
U 50
Accuracy: 0.8771929824561403 Precision: 0.8771929824561403 Recall: 1.0 F1-Score: 0.9345794392523363
N 29
Accuracy: 0.9354838709677419 Precision: 0.9354838709677419 Recall: 1.0 F1-Score: 0.9666666666666666
S 80
Accuracy: 0.9302325581395349 Precision: 0.9302325581395349 Recall: 1.0 F1-Score: 0.963855421686747
O 124
Accuracy: 0.9763779527559056 Precision: 0.9763779527559056 Recall: 1.0 F1-Score: 0.9880478087649402
M 40
Accuracy: 0.9302325581395349 Precision: 0.9302325581395349 Recall: 1.0 F1-Score: 0.963855421686747
B 13
Accuracy: 0.8666666666666667 Precision: 0.8666666666666667 Recall: 1.0 F1-Score: 0.9285714285714286
V 26
Accuracy: 0.9285714285714286 Precision: 0.9285714285714286 Recall: 1.0 F1-Score: 0.962962962962963
X 13
Accuracy: 0.6190476190476191 Precision: 0.6190476190476191 Recall: 1.0 F1-Score: 0.7647058823529412
D 11
Accuracy: 0.6470588235294118 Precision: 0.6470588235294118 Recall: 1.0 F1-Score: 0.7857142857142858
```

```
J 18
Accuracy: 0.8571428571428571 Precision: 0.8571428571428571 Recall: 1.0 F1-Score: 0.923076923076923
H 11
Accuracy: 0.9166666666666666 Precision: 0.9166666666666666 Recall: 1.0 F1-Score: 0.9565217391304348
E 12
Accuracy: 0.631578947368421 Precision: 0.631578947368421 Recall: 1.0 F1-Score: 0.7741935483870968
Q 8
Accuracy: 0.8 Precision: 0.8 Recall: 1.0 F1-Score: 0.8888888888888889
P 36
Accuracy: 0.9 Precision: 0.9 Recall: 1.0 F1-Score: 0.9473684210526316
Y 23
Accuracy: 0.8518518518518519 Precision: 0.8518518518518519 Recall: 1.0 F1-Score: 0.92
W 24
Accuracy: 0.8571428571428571 Precision: 0.8571428571428571 Recall: 1.0 F1-Score: 0.923076923076923
K 15
Accuracy: 0.7894736842105263 Precision: 0.7894736842105263 Recall: 1.0 F1-Score: 0.8823529411764706
L 60
Accuracy: 0.8 Precision: 0.8 Recall: 1.0 F1-Score: 0.8888888888888889
```

SGD 0.01

```
J 18
Accuracy: 0.8571428571428571 Precision: 0.8571428571428571 Recall: 1.0 F1-Score: 0.923076923076923
X 13
Accuracy: 0.6190476190476191 Precision: 0.6190476190476191 Recall: 1.0 F1-Score: 0.7647058823529412
B 13
Accuracy: 0.8666666666666667 Precision: 0.8666666666666667 Recall: 1.0 F1-Score: 0.9285714285714286
C 42
Accuracy: 0.875 Precision: 0.875 Recall: 1.0 F1-Score: 0.9333333333333333
K 15
Accuracy: 0.7894736842105263 Precision: 0.7894736842105263 Recall: 1.0 F1-Score: 0.8823529411764706
Q 8
Accuracy: 0.8 Precision: 0.8 Recall: 1.0 F1-Score: 0.8888888888888889
E 12
Accuracy: 0.631578947368421 Precision: 0.631578947368421 Recall: 1.0 F1-Score: 0.7741935483870968
V 26
Accuracy: 0.9285714285714286 Precision: 0.9285714285714286 Recall: 1.0 F1-Score: 0.962962962962963
L 60
Accuracy: 0.8 Precision: 0.8 Recall: 1.0 F1-Score: 0.8888888888888889
Y 23
Accuracy: 0.8518518518518519 Precision: 0.8518518518518519 Recall: 1.0 F1-Score: 0.92
P 36
Accuracy: 0.9 Precision: 0.9 Recall: 1.0 F1-Score: 0.9473684210526316
W 24
Accuracy: 0.8571428571428571 Precision: 0.8571428571428571 Recall: 1.0 F1-Score: 0.923076923076923
```

```
F 31
Accuracy: 0.9117647058823529 Precision: 0.9117647058823529 Recall: 1.0 F1-Score: 0.9538461538461539
R 14
Accuracy: 0.7368421052631579 Precision: 0.7368421052631579 Recall: 1.0 F1-Score: 0.8484848484848484
S 80
Accuracy: 0.9302325581395349 Precision: 0.9302325581395349 Recall: 1.0 F1-Score: 0.963855421686747
U 50
Accuracy: 0.8771929824561403 Precision: 0.8771929824561403 Recall: 1.0 F1-Score: 0.9345794392523363
Z 16
Accuracy: 0.8 Precision: 0.8 Recall: 1.0 F1-Score: 0.8888888888888889
G 7
Accuracy: 0.7 Precision: 0.7 Recall: 1.0 F1-Score: 0.8235294117647058
A 22
Accuracy: 0.9166666666666666 Precision: 0.9166666666666666 Recall: 1.0 F1-Score: 0.9565217391304348
N 29
Accuracy: 0.9354838709677419 Precision: 0.9354838709677419 Recall: 1.0 F1-Score: 0.9666666666666666
T 36
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
I 99
Accuracy: 0.7071428571428572 Precision: 0.7071428571428572 Recall: 1.0 F1-Score: 0.8284518828451882
O 124
Accuracy: 0.9763779527559056 Precision: 0.9763779527559056 Recall: 1.0 F1-Score: 0.9880478087649402
H 11
Accuracy: 0.9166666666666666 Precision: 0.9166666666666666 Recall: 1.0 F1-Score: 0.9565217391304348
M 40
Accuracy: 0.9302325581395349 Precision: 0.9302325581395349 Recall: 1.0 F1-Score: 0.963855421686747
D 11
Accuracy: 0.6470588235294118 Precision: 0.6470588235294118 Recall: 1.0 F1-Score: 0.7857142857142858
```

SGD 0.1

```
I 0
Accuracy: 0.0
G 0
Accuracy: 0.0
A 24
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
F 0
Accuracy: 0.0
R 0
Accuracy: 0.0
Z 0
Accuracy: 0.0
T 0
Accuracy: 0.0
U 0
Accuracy: 0.0
N 0
Accuracy: 0.0
S 0
Accuracy: 0.0
O 0
Accuracy: 0.0
M 0
Accuracy: 0.0
B 0
Accuracy: 0.0
V 0
Accuracy: 0.0
X 0
Accuracy: 0.0
D 0
Accuracy: 0.0
```

```
J 0
Accuracy: 0.0
H 0
Accuracy: 0.0
E 0
Accuracy: 0.0
Q 0
Accuracy: 0.0
P 0
Accuracy: 0.0
Y 0
Accuracy: 0.0
W 0
Accuracy: 0.0
K 0
Accuracy: 0.0
L 0
Accuracy: 0.0
```

ADAM 0.001

```
I 140
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
G 0
Accuracy: 0.0
A 0
Accuracy: 0.0
F 0
Accuracy: 0.0
R 0
Accuracy: 0.0
Z 0
Accuracy: 0.0
T 0
Accuracy: 0.0
U 0
Accuracy: 0.0
N 0
Accuracy: 0.0
S 0
Accuracy: 0.0
O 0
Accuracy: 0.0
M 0
Accuracy: 0.0
B 0
Accuracy: 0.0
V 0
Accuracy: 0.0
X 0
Accuracy: 0.0
D 0
Accuracy: 0.0
```

```
D 0
Accuracy: 0.0
J 0
Accuracy: 0.0
H 0
Accuracy: 0.0
E 0
Accuracy: 0.0
Q 0
Accuracy: 0.0
P 0
Accuracy: 0.0
Y 0
Accuracy: 0.0
W 0
Accuracy: 0.0
K 0
Accuracy: 0.0
L 0
Accuracy: 0.0
```

ADAM 0.01

```
I 140
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
G 0
Accuracy: 0.0
A 0
Accuracy: 0.0
F 0
Accuracy: 0.0
R 0
Accuracy: 0.0
Z 0
Accuracy: 0.0
T 0
Accuracy: 0.0
U 0
Accuracy: 0.0
N 0
Accuracy: 0.0
S 0
Accuracy: 0.0
O 0
Accuracy: 0.0
M 0
Accuracy: 0.0
B 0
Accuracy: 0.0
V 0
Accuracy: 0.0
X 0
Accuracy: 0.0
D 0
Accuracy: 0.0
```

```
J 0
Accuracy: 0.0
H 0
Accuracy: 0.0
E 0
Accuracy: 0.0
Q 0
Accuracy: 0.0
P 0
Accuracy: 0.0
Y 0
Accuracy: 0.0
W 0
Accuracy: 0.0
K 0
Accuracy: 0.0
L 0
Accuracy: 0.0
```

```
U 0
Accuracy: 0.0
A 24
Accuracy: 1.0 Precision: 1.0 Recall: 1.0 F1-Score: 1.0
S 0
Accuracy: 0.0
N 0
Accuracy: 0.0
G 0
Accuracy: 0.0
R 0
Accuracy: 0.0
T 0
Accuracy: 0.0
I 0
Accuracy: 0.0
F 0
Accuracy: 0.0
O 0
Accuracy: 0.0
H 0
Accuracy: 0.0
X 0
Accuracy: 0.0
E 0
Accuracy: 0.0
V 0
Accuracy: 0.0
C 0
Accuracy: 0.0
M 0
```

```
B 0
Accuracy: 0.0
Q 0
Accuracy: 0.0
D 0
Accuracy: 0.0
K 0
Accuracy: 0.0
L 0
Accuracy: 0.0
Y 0
Accuracy: 0.0
W 0
Accuracy: 0.0
P 0
Accuracy: 0.0
```

ADAM 0.1

Result:

We experimented with different optimizers and learning rates and got the following results:

Training accuracy:

INCEPTIONV3	Learning Rate - 0.001	Learning Rate - 0.01	Learning Rate - 0.1
SGD Optimizer	99%	95%	85.85%
Adam Optimizer	78.21%	81%	44%

VGG16	Learning Rate - 0.001	Learning Rate - 0.01	Learning Rate - 0.1
SGD Optimizer			
Adam Optimizer			

VGG16	Learning Rate - 0.001	Learning Rate - 0.01	Learning Rate - 0.1
SGD Optimizer	92.88%	97.31%	2.37%
Adam Optimizer	14.59%	13.47%	2%

Testing accuracy:

INCEPTIONV3	Learning Rate - 0.001	Learning Rate - 0.01	Learning Rate - 0.1
SGD Optimizer	84.11%	80.73%	72.09%
Adam Optimizer	62.76%	61.66%	56.70%

VGG16	Learning Rate - 0.001	Learning Rate - 0.01	Learning Rate - 0.1
SGD Optimizer	85.29%	85.4%	2.5%
Adam Optimizer	14.10%	14.5%	2.38%

Validation accuracy:

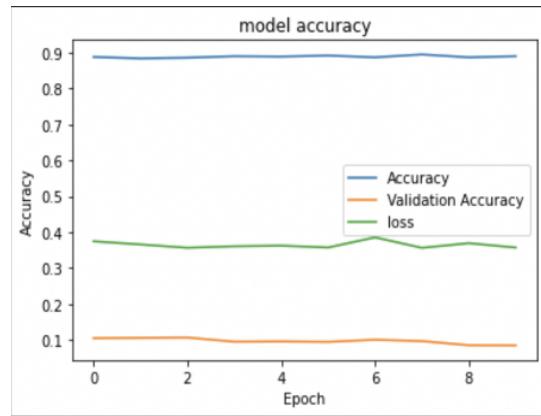
INCEPTIONV3	Learning Rate - 0.001	Learning Rate - 0.01	Learning Rate - 0.1
SGD Optimizer	88.98%	82.13%	78.11%
Adam Optimizer	30.8%	14%	13.90%

VGG16	Learning Rate - 0.001	Learning Rate - 0.01	Learning Rate - 0.1
SGD Optimizer	80.73%	85.25%	2.38%
Adam Optimizer	13.9%	13.47%	2.36%

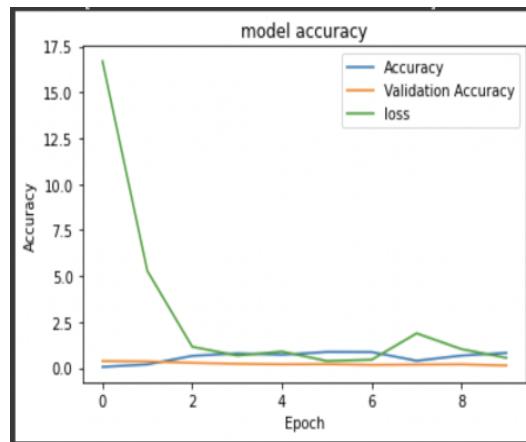
A) The graphs obtained by plotting the loss, accuracy, validation accuracy against the epochs while training the InceptionV3 models.

Optimiser:

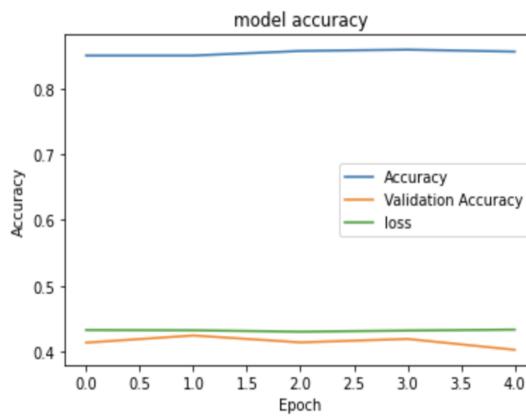
1. Stochastic Gradient Descent (Sgd)
 - a. Learning rate - 0.001



b. Learning rate - 0.01

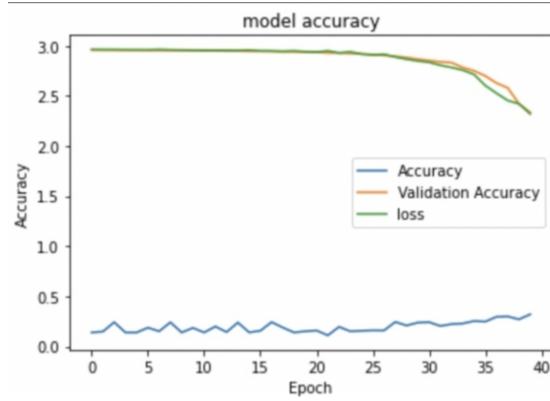


c. Learning rate - 0.1

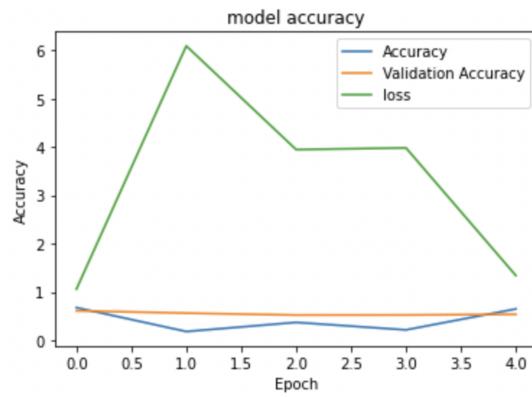


2. Adam

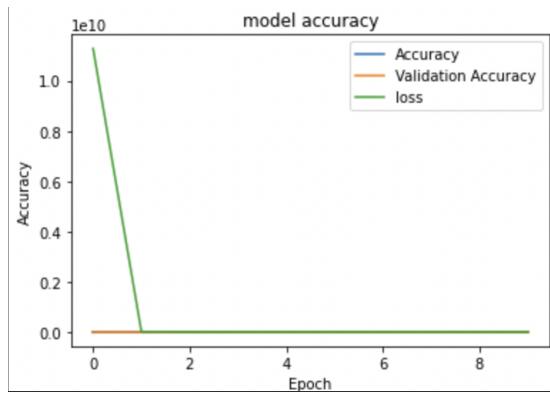
a. Learning rate - 0.001



b. Learning rate - 0.01



c. Learning rate - 0.1

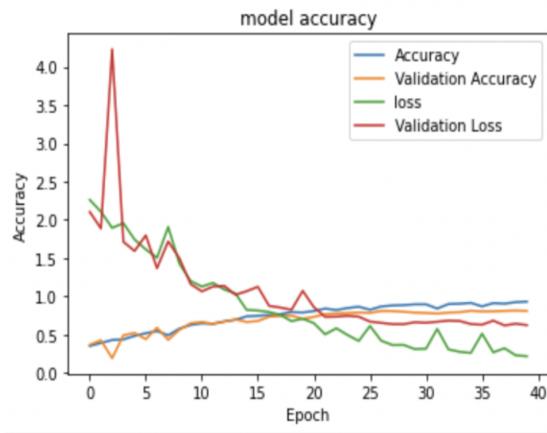


B) The graphs obtained by plotting the loss, accuracy, validation accuracy against the epochs while training the VGG16 InceptionV3 models.

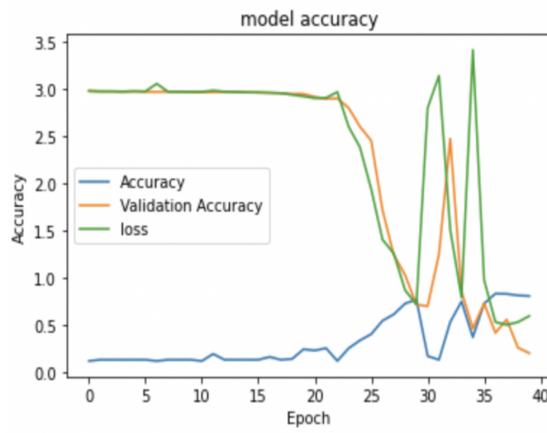
Optimiser:

1. Stochastic Gradient Descent (Sgd)

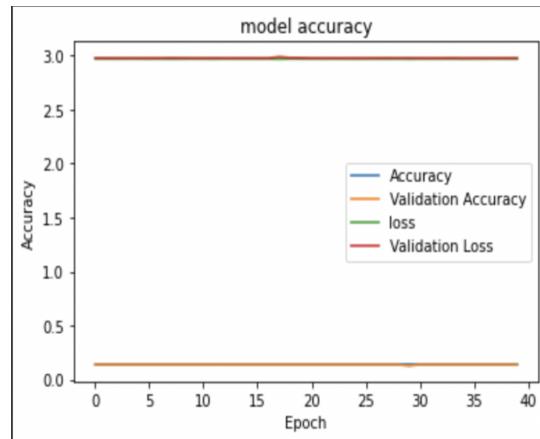
a. Learning rate - 0.001



b. Learning rate - 0.01

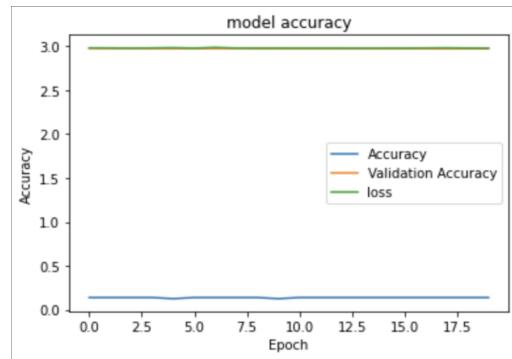


c. Learning rate- 0.1

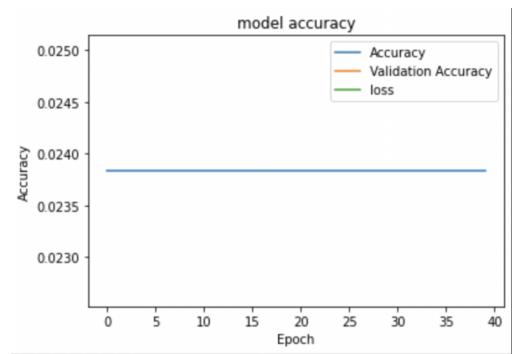


2. Adam

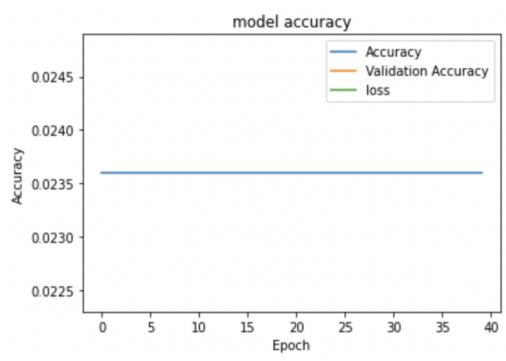
a. Learning rate- 0.1



b. Learning rate-0.01



c. Learning rate-0.1



References:

- [1]<https://arxiv.org/pdf/1512.00567v3.pdf>
- [2]<https://blog.paperspace.com/popular-deep-learning-architectures-resnet-inceptionv3-squeeze/>
- [3]https://www.google.com/url?sa=i&url=https%3A%2F%2Ftowardsdatascience.com%2Fstep-by-step-vgg16-implementation-in-keras-for-beginners-a833c686ae6c&psig=AOvVaw1HuZ0DG-SS9PXVHXHT0tZX&ust=1654373561350000&source=images&cd=vfe&ved=0CAwQjRxqFwoTCIDXz_WLkvgCFQAAAAAdAAAAABAD