Assignment 6

Link to questions - here

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Project Setup

Mount Google Drive

```
Mounted at /content/gdrive
```

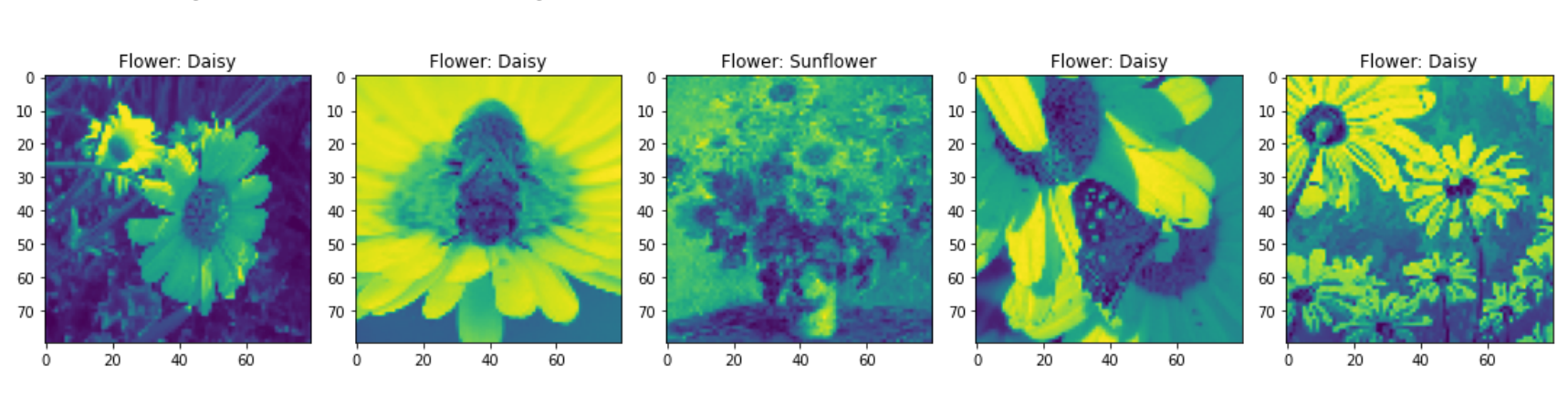
Importing all necessary libraries

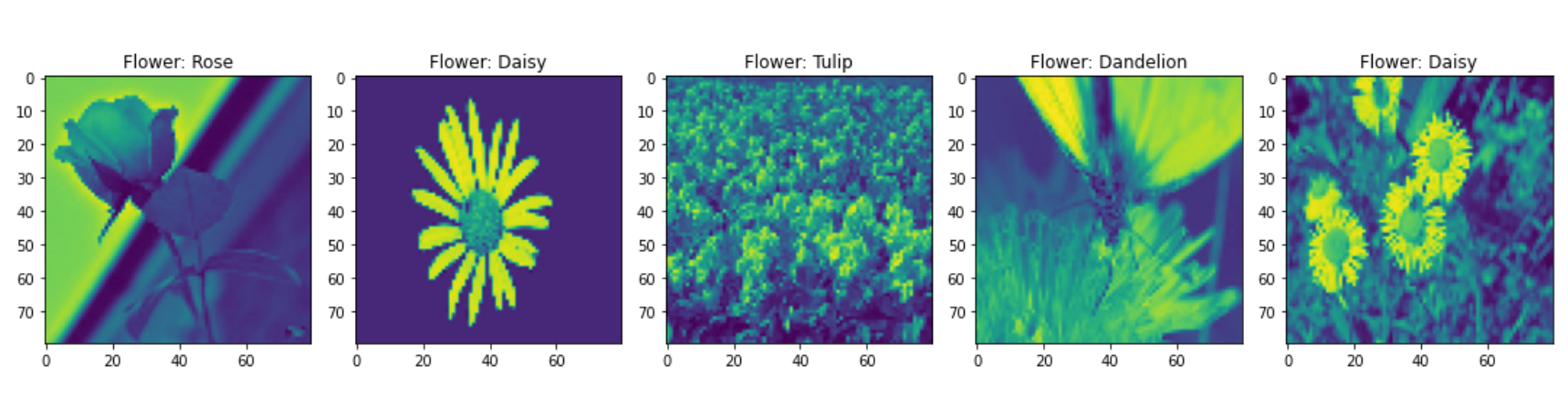
Data-Loading

Create training data

Define helper functions for plotting accuracy, loss, confusion matrix for all models

Visualizing some of the images we loaded





Pre-processing

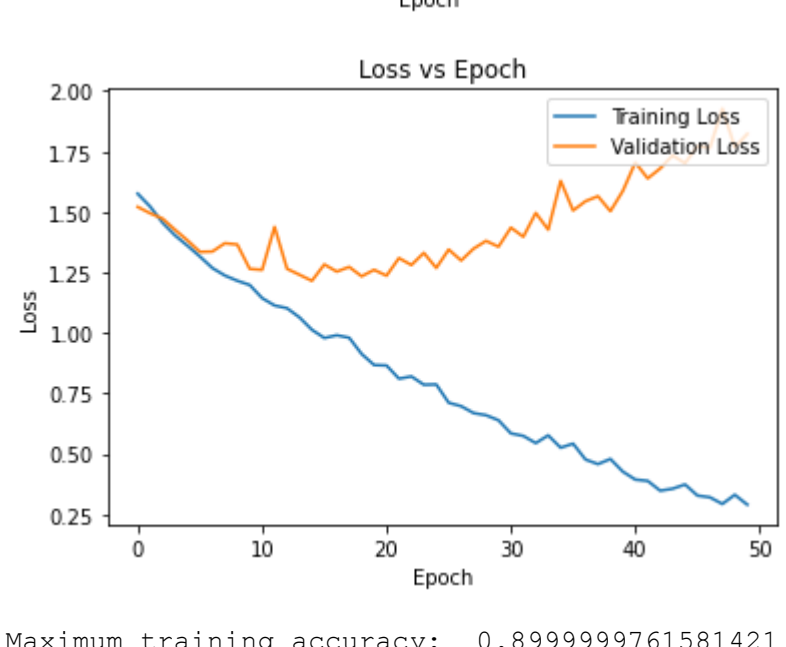
One-Hot Encoding

Train : Test split

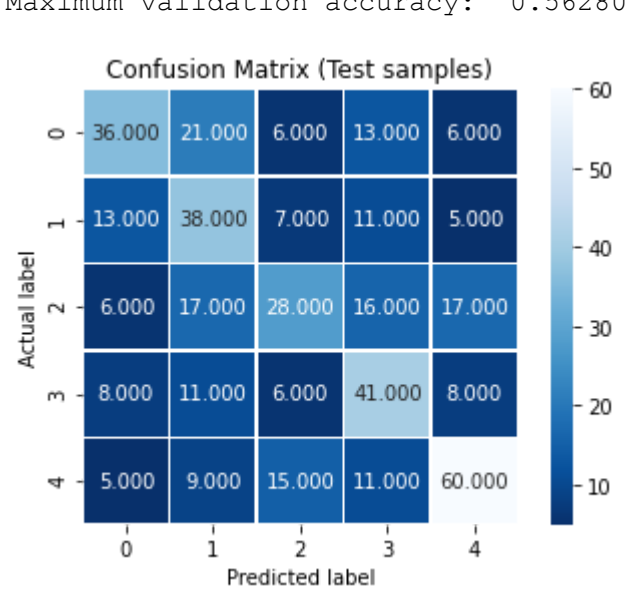
Trying out the initial 4 models

Model 1

```
Model: "sequential"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d (Conv2D)              (None, 80, 80, 16)        160
_________________________________________________________________
max_pooling2d (MaxPooling2D) (None, 40, 40, 16)        0
_________________________________________________________________
dropout (Dropout)            (None, 40, 40, 16)        0
_________________________________________________________________
conv2d_1 (Conv2D)            (None, 40, 40, 32)        4640
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 20, 20, 32)        0
_________________________________________________________________
dropout_1 (Dropout)          (None, 20, 20, 32)        0
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 20, 20, 64)        18496
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 10, 10, 64)        0
_________________________________________________________________
dropout_2 (Dropout)          (None, 10, 10, 64)        0
_________________________________________________________________
flatten (Flatten)            (None, 6400)              0
_________________________________________________________________
dense (Dense)                (None, 5)                 32005
=================================================================
Total params: 55,301
Trainable params: 55,301
Non-trainable params: 0
_________________________________________________________________
```



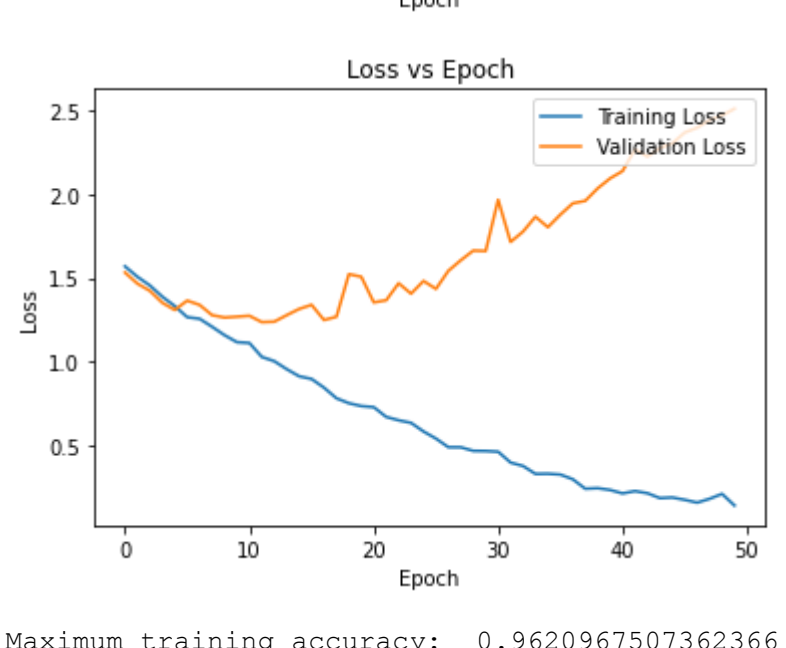

```
Maximum training accuracy:  0.8999999761581421
Maximum validation accuracy:  0.5628019571304321
```



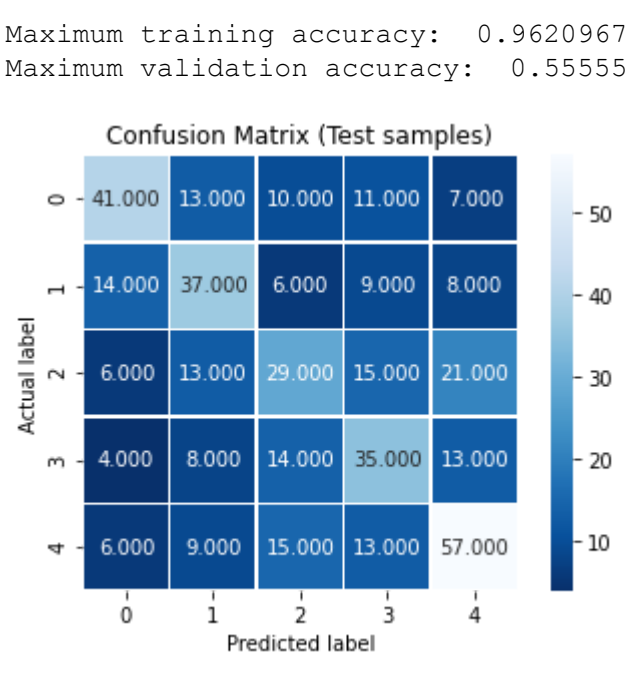

```
              precision    recall  f1-score   support

           0       0.53      0.44      0.48        82
           1       0.40      0.51      0.45        74
           2       0.45      0.33      0.38        84
           3       0.45      0.55      0.49        74
           4       0.62      0.60      0.61       100

    accuracy                           0.49       414
   macro avg       0.49      0.49      0.48       414
weighted avg       0.50      0.49      0.49       414
```

Model 2

```
Model: "sequential_1"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_3 (Conv2D)            (None, 80, 80, 16)        160
_________________________________________________________________
max_pooling2d_3 (MaxPooling2 (None, 40, 40, 16)        0
_________________________________________________________________
dropout_3 (Dropout)          (None, 40, 40, 16)        0
_________________________________________________________________
conv2d_4 (Conv2D)            (None, 40, 40, 32)        4640
_________________________________________________________________
max_pooling2d_4 (MaxPooling2 (None, 20, 20, 32)        0
_________________________________________________________________
dropout_4 (Dropout)          (None, 20, 20, 32)        0
_________________________________________________________________
conv2d_5 (Conv2D)            (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_5 (MaxPooling2 (None, 10, 10, 64)        0
_________________________________________________________________
dropout_5 (Dropout)          (None, 10, 10, 64)        0
_________________________________________________________________
flatten_1 (Flatten)          (None, 6400)              0
_________________________________________________________________
dense_1 (Dense)              (None, 5)                 32005
=================================================================
Total params: 88,069
Trainable params: 88,069
Non-trainable params: 0
_________________________________________________________________
```



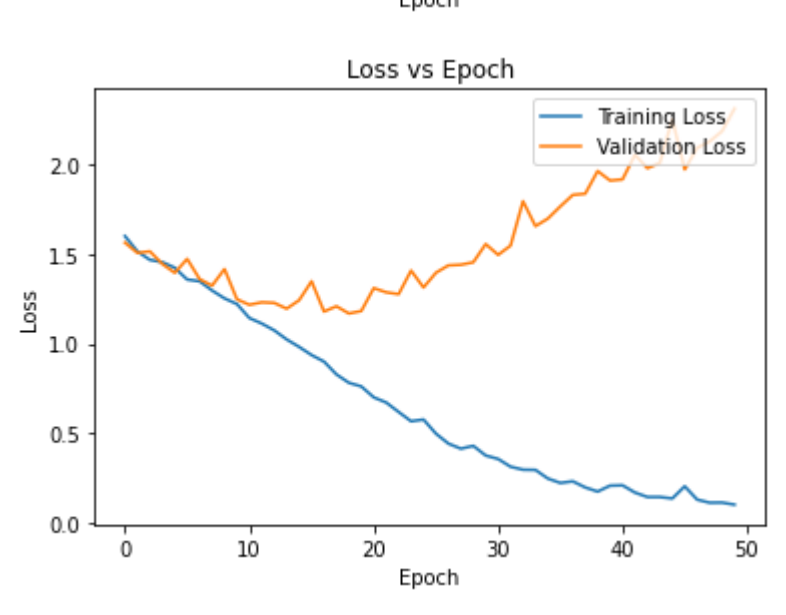

```
Maximum training accuracy:  0.9620967507362366
Maximum validation accuracy:  0.5555555820465088
```



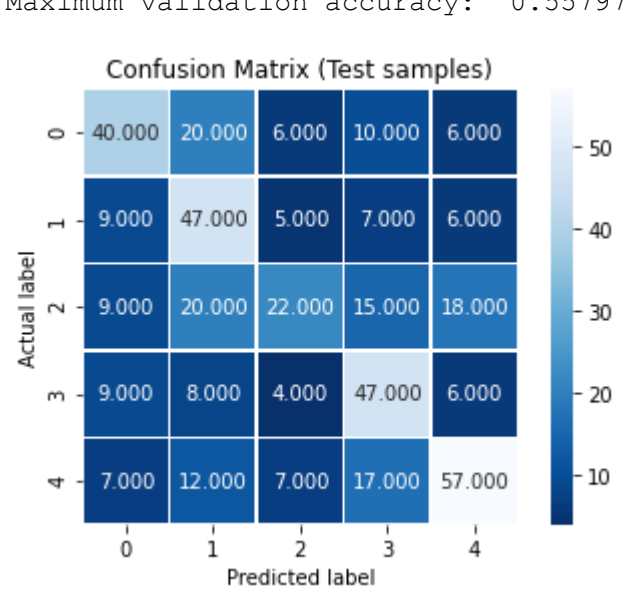

```
              precision    recall  f1-score   support

           0       0.58      0.50      0.54        82
           1       0.46      0.50      0.48        74
           2       0.39      0.35      0.37        84
           3       0.42      0.47      0.45        74
           4       0.54      0.57      0.55       100

    accuracy                           0.48       414
   macro avg       0.48      0.48      0.48       414
weighted avg       0.48      0.48      0.48       414
```

Model 3

```
Model: "sequential_2"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_6 (Conv2D)            (None, 80, 80, 16)        160
_________________________________________________________________
max_pooling2d_6 (MaxPooling2 (None, 40, 40, 16)        0
_________________________________________________________________
dropout_6 (Dropout)          (None, 40, 40, 16)        0
_________________________________________________________________
conv2d_7 (Conv2D)            (None, 40, 40, 32)        12832
_________________________________________________________________
max_pooling2d_7 (MaxPooling2 (None, 20, 20, 32)        0
_________________________________________________________________
dropout_7 (Dropout)          (None, 20, 20, 32)        0
_________________________________________________________________
conv2d_8 (Conv2D)            (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_8 (MaxPooling2 (None, 10, 10, 64)        0
_________________________________________________________________
dropout_8 (Dropout)          (None, 10, 10, 64)        0
_________________________________________________________________
flatten_2 (Flatten)          (None, 6400)              0
_________________________________________________________________
dense_2 (Dense)              (None, 5)                 32005
=================================================================
Total params: 96,261
Trainable params: 96,261
Non-trainable params: 0
_________________________________________________________________
```



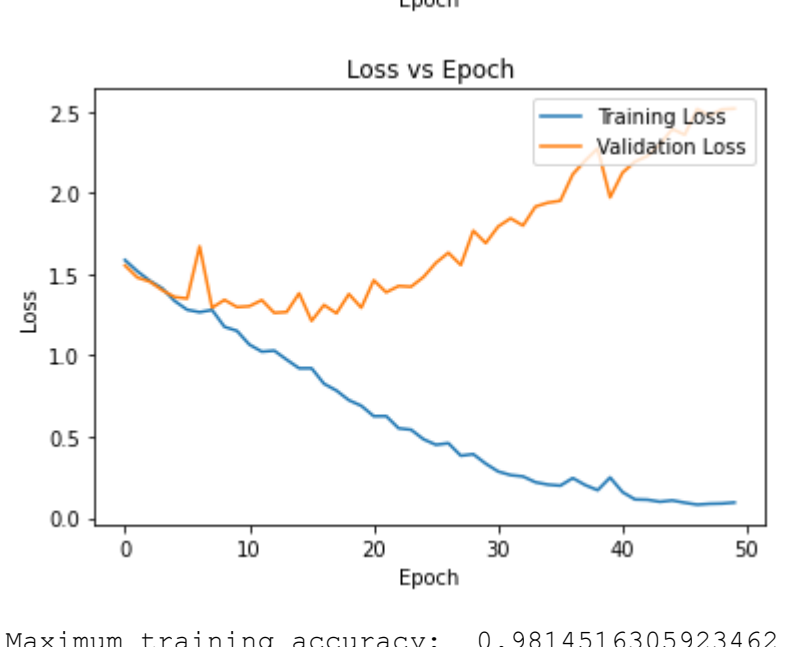

```
Maximum training accuracy:  0.9701613187789917
Maximum validation accuracy:  0.5579710006713867
```



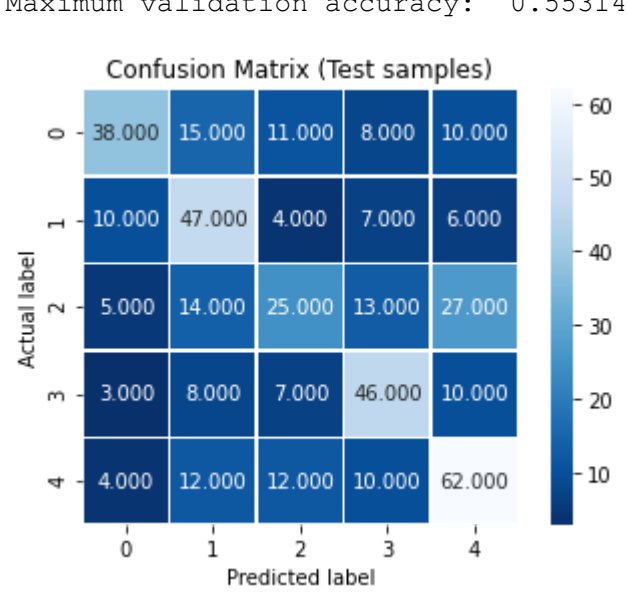

```
              precision    recall  f1-score   support

           0       0.54      0.49      0.51        82
           1       0.44      0.64      0.52        74
           2       0.50      0.26      0.34        84
           3       0.49      0.64      0.55        74
           4       0.61      0.57      0.59       100

    accuracy                           0.51       414
   macro avg       0.52      0.52      0.50       414
weighted avg       0.52      0.51      0.51       414
```

Model 4

```
Model: "sequential_3"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_9 (Conv2D)            (None, 80, 80, 16)        416
_________________________________________________________________
max_pooling2d_9 (MaxPooling2 (None, 40, 40, 16)        0
_________________________________________________________________
dropout_9 (Dropout)          (None, 40, 40, 16)        0
_________________________________________________________________
conv2d_10 (Conv2D)           (None, 40, 40, 32)        12832
_________________________________________________________________
max_pooling2d_10 (MaxPooling (None, 20, 20, 32)        0
_________________________________________________________________
dropout_10 (Dropout)         (None, 20, 20, 32)        0
_________________________________________________________________
conv2d_11 (Conv2D)           (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_11 (MaxPooling (None, 10, 10, 64)        0
_________________________________________________________________
dropout_11 (Dropout)         (None, 10, 10, 64)        0
_________________________________________________________________
flatten_3 (Flatten)          (None, 6400)              0
_________________________________________________________________
dense_3 (Dense)              (None, 5)                 32005
=================================================================
Total params: 96,517
Trainable params: 96,517
Non-trainable params: 0
_________________________________________________________________
```




```
Maximum training accuracy:  0.9814516305923462
Maximum validation accuracy:  0.5531401038169861
```




```
              precision    recall  f1-score   support

           0       0.63      0.46      0.54        82
           1       0.49      0.64      0.55        74
           2       0.42      0.30      0.35        84
           3       0.55      0.62      0.58        74
           4       0.54      0.62      0.58       100

    accuracy                           0.53       414
   macro avg       0.53      0.53      0.52       414
weighted avg       0.53      0.53      0.52       414
```

Model 3 was the best model with an accuracy of 57.84% on the validation dataset.

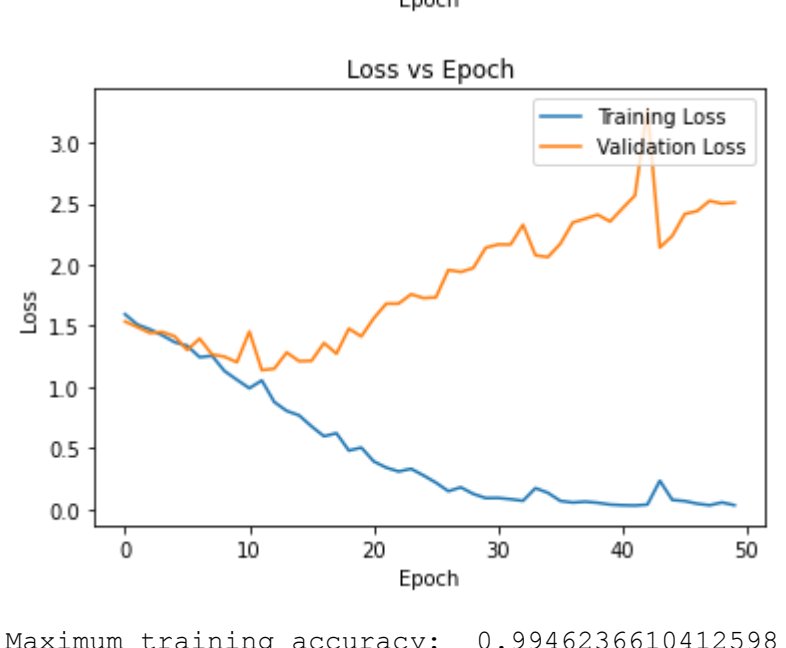
The model is as follows:

```
model3 = Sequential()

model3.add(Conv2D(filters = 16, kernel_size = (3,3),padding = 'Same',activation ='relu', input_shape = (80,80,1)))
model3.add(MaxPooling2D(pool_size=(2, 2)))
model3.add(Dropout(0.1))

model3.add(Conv2D(filters = 32, kernel_size = (5,5),padding = 'Same',activation ='relu'))
model3.add(MaxPooling2D(pool_size=(2, 2)))
model3.add(Dropout(0.1))

model3.add(Conv2D(filters = 64, kernel_size = (5,5),padding = 'Same',activation ='relu'))
model3.add(MaxPooling2D(pool_size=(2, 2)))
model3.add(Dropout(0.1))

model3.add(Flatten())
model3.add(Dense(5, activation = 'softmax'))

model3.compile(optimizer=Adam(),loss='categorical_crossentropy',metrics=['accuracy'])
model3.summary()
```

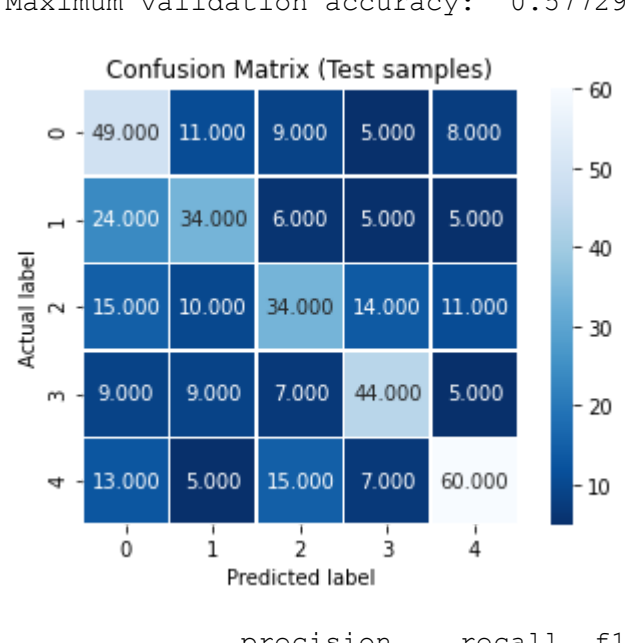
Now, we will be adding 2/3 fully-connected layers to this model.

Model 5

```
Model: "sequential_4"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_12 (Conv2D)           (None, 80, 80, 16)        160
_________________________________________________________________
max_pooling2d_12 (MaxPooling (None, 40, 40, 16)        0
_________________________________________________________________
dropout_12 (Dropout)         (None, 40, 40, 16)        0
_________________________________________________________________
conv2d_13 (Conv2D)           (None, 40, 40, 32)        12832
_________________________________________________________________
max_pooling2d_13 (MaxPooling (None, 20, 20, 32)        0
_________________________________________________________________
dropout_13 (Dropout)         (None, 20, 20, 32)        0
_________________________________________________________________
conv2d_14 (Conv2D)           (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_14 (MaxPooling (None, 10, 10, 64)        0
_________________________________________________________________
dropout_14 (Dropout)         (None, 10, 10, 64)        0
_________________________________________________________________
flatten_4 (Flatten)          (None, 6400)              0
_________________________________________________________________
dense_4 (Dense)              (None, 128)               819328
_________________________________________________________________
dense_5 (Dense)              (None, 5)                 645
=================================================================
Total params: 884,229
Trainable params: 884,229
Non-trainable params: 0
_________________________________________________________________
```



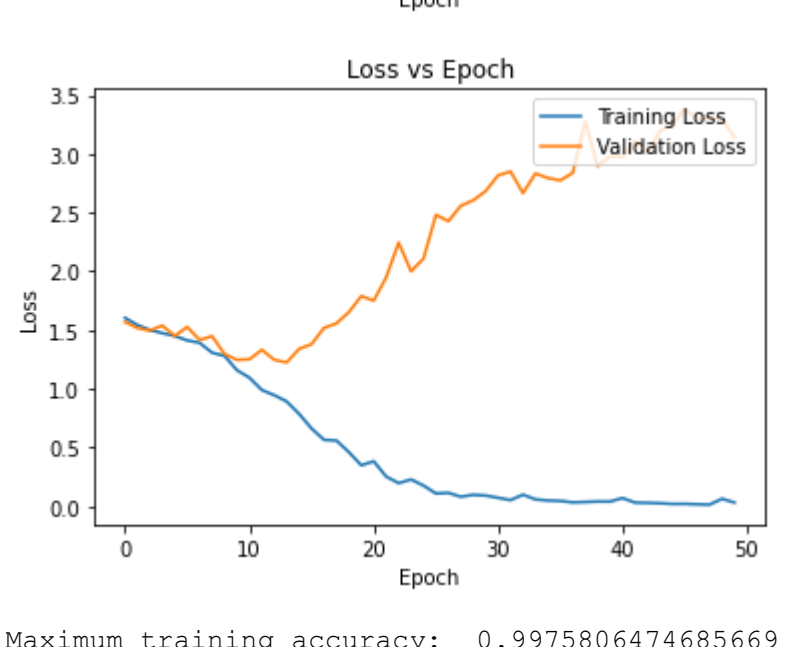

```
Maximum training accuracy:  0.9946236610412598
Maximum validation accuracy:  0.5772947072982788
```



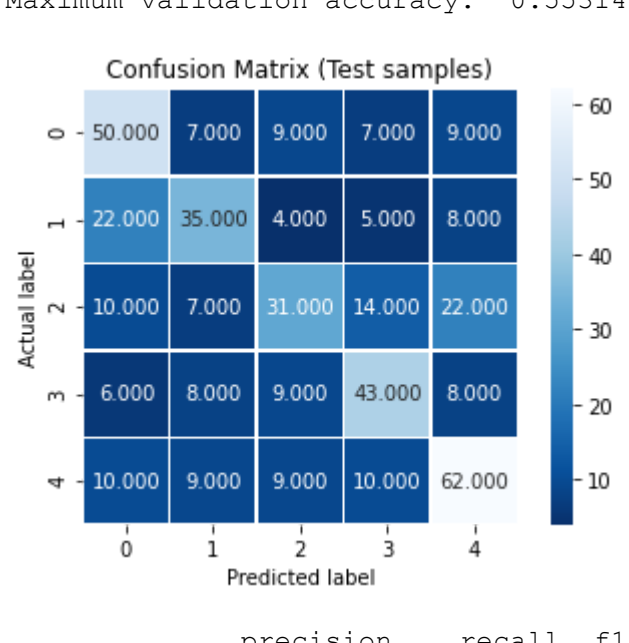

```
              precision    recall  f1-score   support

           0       0.45      0.60      0.51        82
           1       0.49      0.46      0.48        74
           2       0.48      0.40      0.44        84
           3       0.59      0.59      0.59        74
           4       0.67      0.60      0.63       100

    accuracy                           0.53       414
   macro avg       0.54      0.53      0.53       414
weighted avg       0.54      0.53      0.53       414
```

Model 6

```
Model: "sequential_5"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_15 (Conv2D)           (None, 80, 80, 16)        160
_________________________________________________________________
max_pooling2d_15 (MaxPooling (None, 40, 40, 16)        0
_________________________________________________________________
dropout_15 (Dropout)         (None, 40, 40, 16)        0
_________________________________________________________________
conv2d_16 (Conv2D)           (None, 40, 40, 32)        12832
_________________________________________________________________
max_pooling2d_16 (MaxPooling (None, 20, 20, 32)        0
_________________________________________________________________
dropout_16 (Dropout)         (None, 20, 20, 32)        0
_________________________________________________________________
conv2d_17 (Conv2D)           (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_17 (MaxPooling (None, 10, 10, 64)        0
_________________________________________________________________
dropout_17 (Dropout)         (None, 10, 10, 64)        0
_________________________________________________________________
flatten_5 (Flatten)          (None, 6400)              0
_________________________________________________________________
dense_6 (Dense)              (None, 128)               819328
_________________________________________________________________
dense_7 (Dense)              (None, 256)               33024
_________________________________________________________________
dense_8 (Dense)              (None, 5)                 1285
=================================================================
Total params: 917,893
Trainable params: 917,893
Non-trainable params: 0
_________________________________________________________________
```




```
Maximum training accuracy:  0.9975806474685669
Maximum validation accuracy:  0.5531401038169861
```




```
              precision    recall  f1-score   support

           0       0.51      0.61      0.56        82
           1       0.53      0.47      0.50        74
           2       0.50      0.37      0.42        84
           3       0.54      0.58      0.56        74
           4       0.57      0.62      0.59       100

    accuracy                           0.53       414
   macro avg       0.53      0.53      0.53       414
weighted avg       0.53      0.53      0.53       414
```

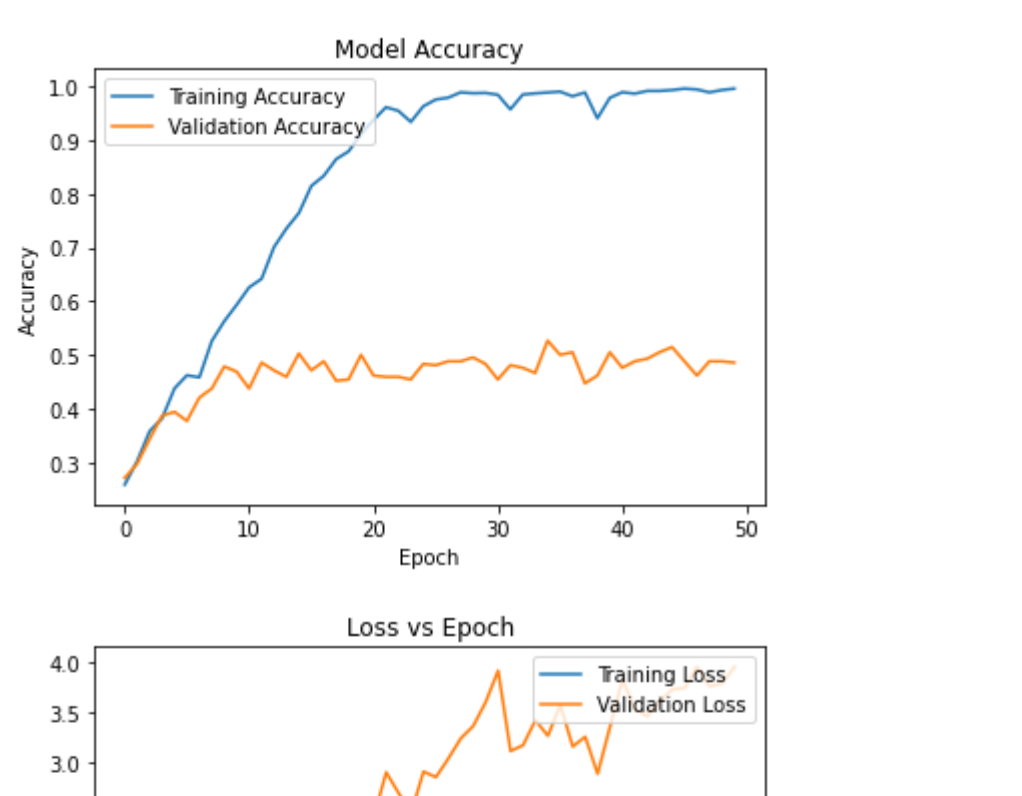
Model 6 is the best model with an accuracy of 58.82% on the validation dataset.

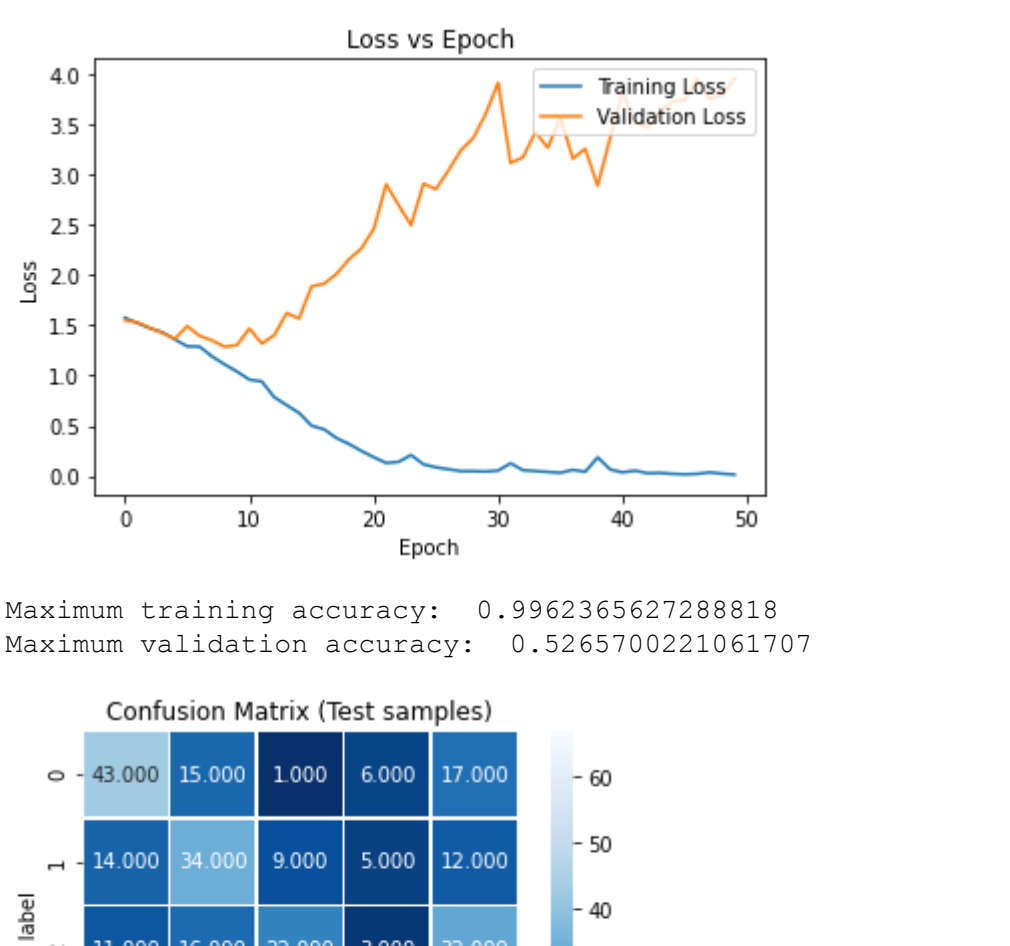
```
model6 = Sequential()

model6.add(Conv2D(filters = 16, kernel_size = (3,3),padding = 'Same',activation ='relu', input_shape = (80,80,1)))
model6.add(MaxPooling2D(pool_size=(2, 2)))
model6.add(Dropout(0.1))

model6.add(Conv2D(filters = 32, kernel_size = (5,5),padding = 'Same',activation ='relu'))
model6.add(MaxPooling2D(pool_size=(2, 2)))
model6.add(Dropout(0.1))
model6.add(Conv2D(filters = 64, kernel_size = (5,5),padding = 'Same',activation ='relu'))
model6.add(MaxPooling2D(pool_size=(2, 2)))
model6.add(Dropout(0.1))

model6.add(Flatten())
model6.add(Dense(128, activation = 'relu'))
model6.add(Dense(256, activation = 'relu'))
model6.add(Dense(5, activation = 'softmax'))

model6.compile(optimizer=Adam(),loss='categorical_crossentropy',metrics=['accuracy'])
model6.summary()
```

Now, we will be trying out average pooling on the same model instead of max pooling.

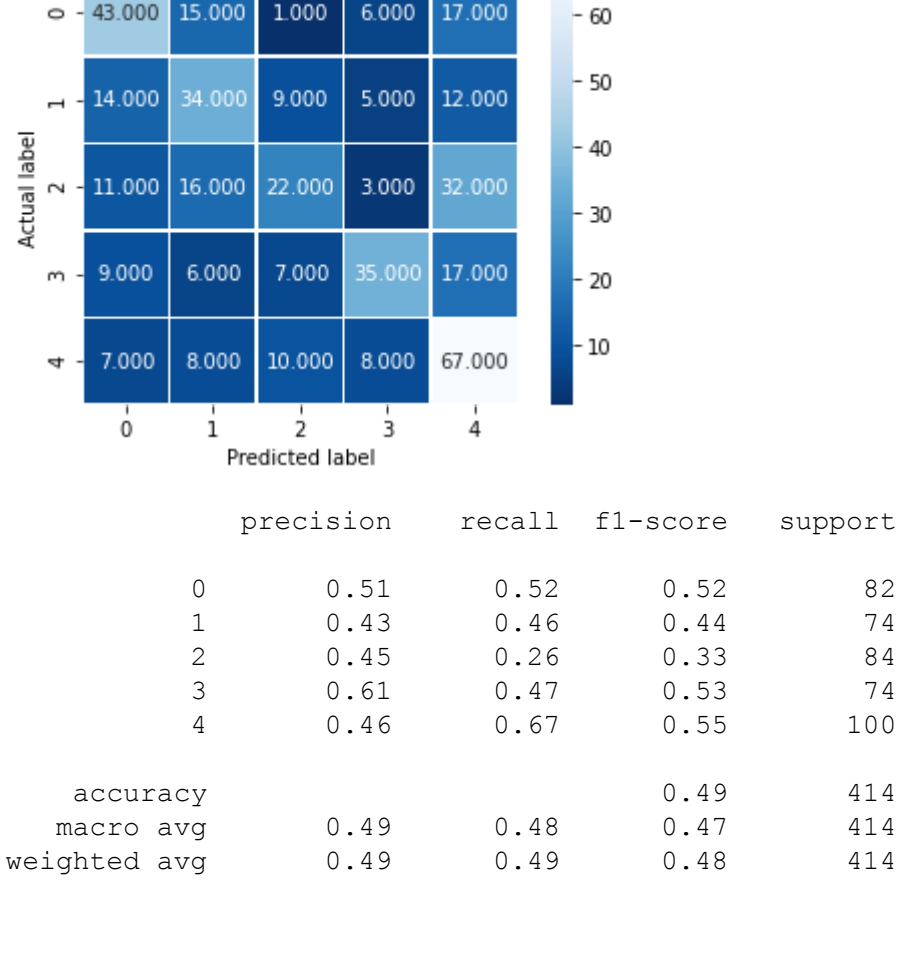
Model 7

```
Model: "sequential_6"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_18 (Conv2D)           (None, 80, 80, 16)        160
_________________________________________________________________
average_pooling2d (AveragePo (None, 40, 40, 16)        0
_________________________________________________________________
dropout_18 (Dropout)         (None, 40, 40, 16)        0
_________________________________________________________________
conv2d_19 (Conv2D)           (None, 40, 40, 32)        12832
_________________________________________________________________
average_pooling2d_1 (Average (None, 20, 20, 32)        0
_________________________________________________________________
dropout_19 (Dropout)         (None, 20, 20, 32)        0
_________________________________________________________________
conv2d_20 (Conv2D)           (None, 20, 20, 64)        51264
_________________________________________________________________
average_pooling2d_2 (Average (None, 10, 10, 64)        0
_________________________________________________________________
dropout_20 (Dropout)         (None, 10, 10, 64)        0
_________________________________________________________________
flatten_6 (Flatten)          (None, 6400)              0
_________________________________________________________________
dense_9 (Dense)              (None, 128)               819328
_________________________________________________________________
dense_10 (Dense)             (None, 256)               33024
_________________________________________________________________
dense_11 (Dense)             (None, 5)                 1285
=================================================================
Total params: 917,893
Trainable params: 917,893
Non-trainable params: 0
_________________________________________________________________
```






```
Maximum training accuracy:  0.9962365627288818
Maximum validation accuracy:  0.5265700221061707
```

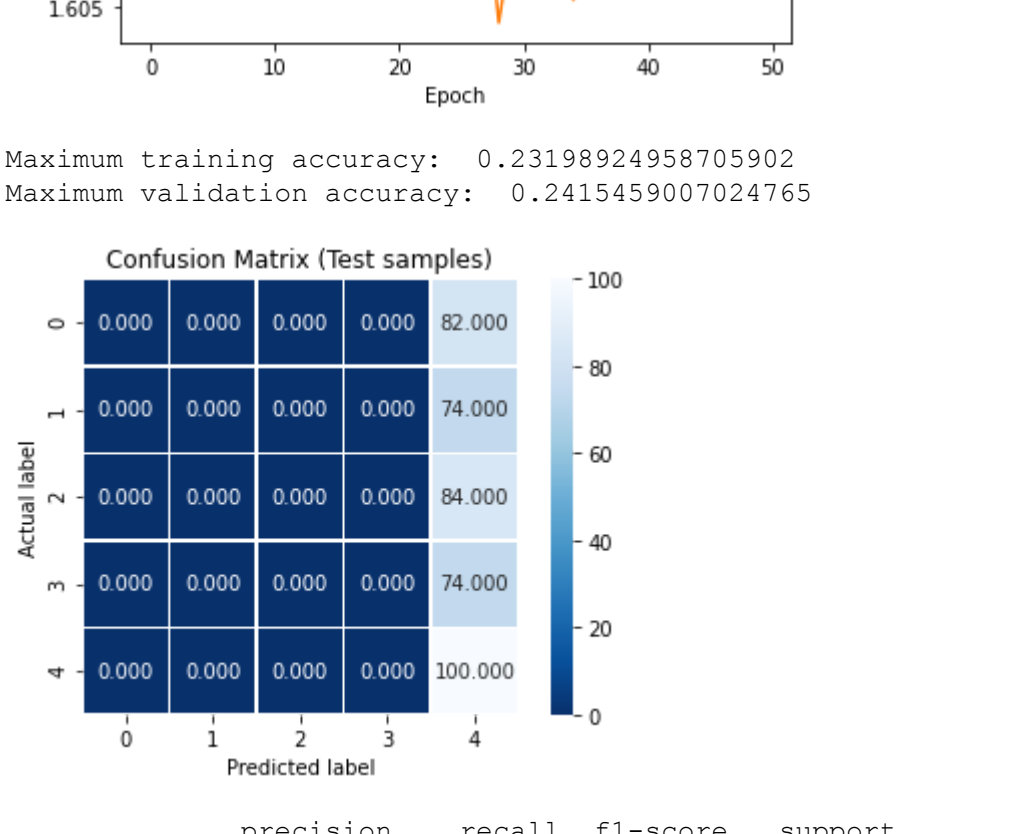


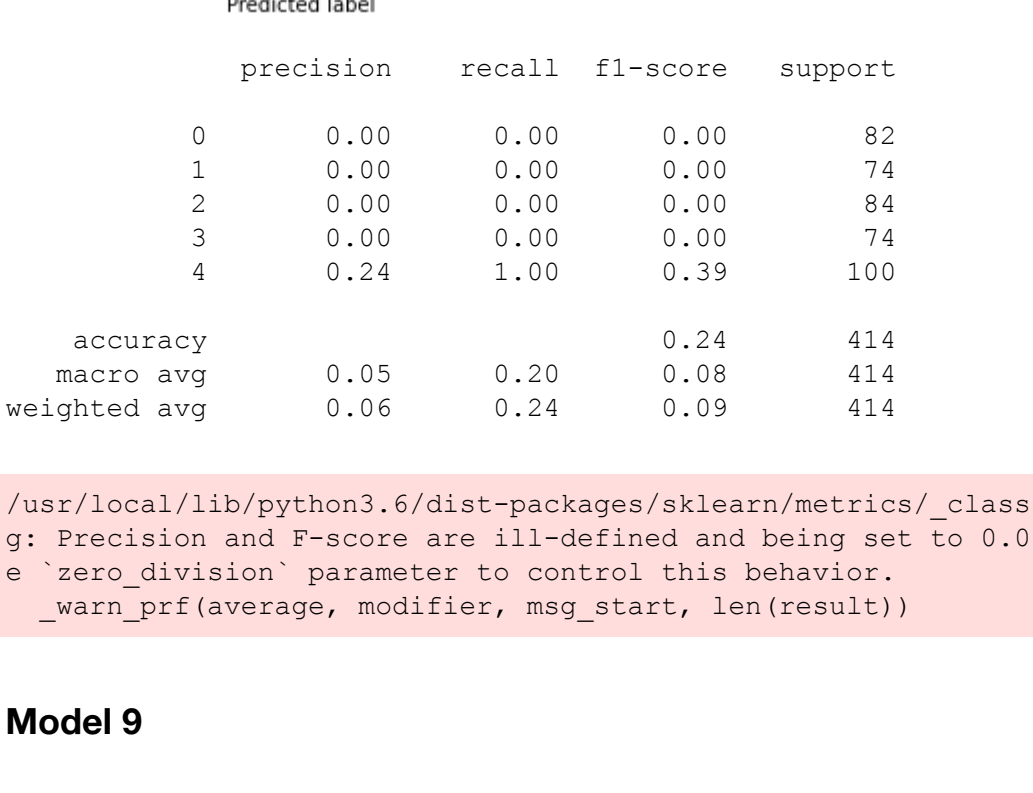

```
              precision    recall  f1-score   support

           0       0.51      0.52      0.52        82
           1       0.43      0.46      0.44        74
           2       0.45      0.26      0.33        84
           3       0.61      0.47      0.53        74
           4       0.46      0.67      0.55       100

    accuracy                           0.49       414
   macro avg       0.49      0.48      0.47       414
weighted avg       0.49      0.49      0.48       414
```

We see that average pooling does not give us better results than max pooling. Hence, we stick with model 6 and vary the activation functions to see which one performs better on model 6.

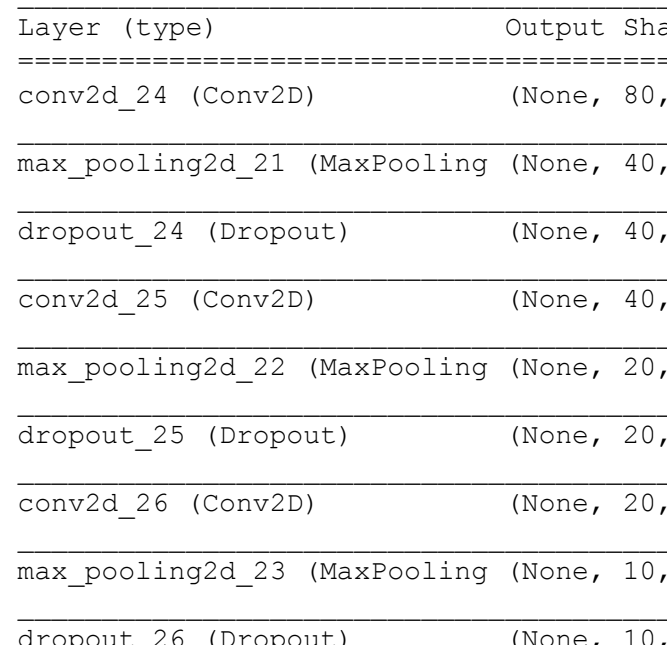
Model 8

```
Model: "sequential_7"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_21 (Conv2D)           (None, 80, 80, 16)        160
_________________________________________________________________
max_pooling2d_18 (MaxPooling (None, 40, 40, 16)        0
_________________________________________________________________
dropout_21 (Dropout)         (None, 40, 40, 16)        0
_________________________________________________________________
conv2d_22 (Conv2D)           (None, 40, 40, 32)        12832
_________________________________________________________________
max_pooling2d_19 (MaxPooling (None, 20, 20, 32)        0
_________________________________________________________________
dropout_22 (Dropout)         (None, 20, 20, 32)        0
_________________________________________________________________
conv2d_23 (Conv2D)           (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_20 (MaxPooling (None, 10, 10, 64)        0
_________________________________________________________________
dropout_23 (Dropout)         (None, 10, 10, 64)        0
_________________________________________________________________
flatten_7 (Flatten)          (None, 6400)              0
_________________________________________________________________
dense_12 (Dense)             (None, 128)               819328
_________________________________________________________________
dense_13 (Dense)             (None, 256)               33024
_________________________________________________________________
dense_14 (Dense)             (None, 5)                 1285
=================================================================
Total params: 917,893
Trainable params: 917,893
Non-trainable params: 0
_________________________________________________________________
```






```
Maximum training accuracy:  0.23198924958705902
Maximum validation accuracy:  0.2415459007024765
```

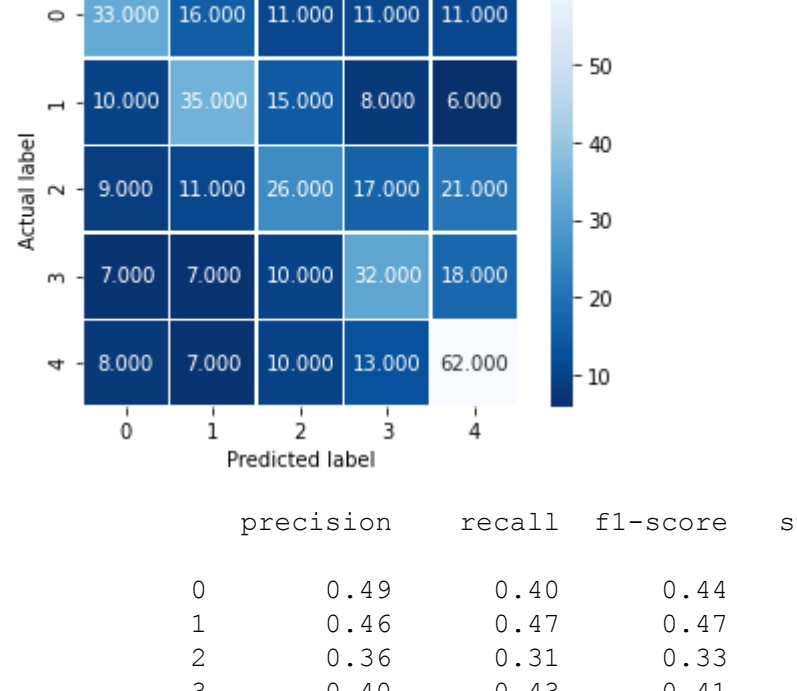


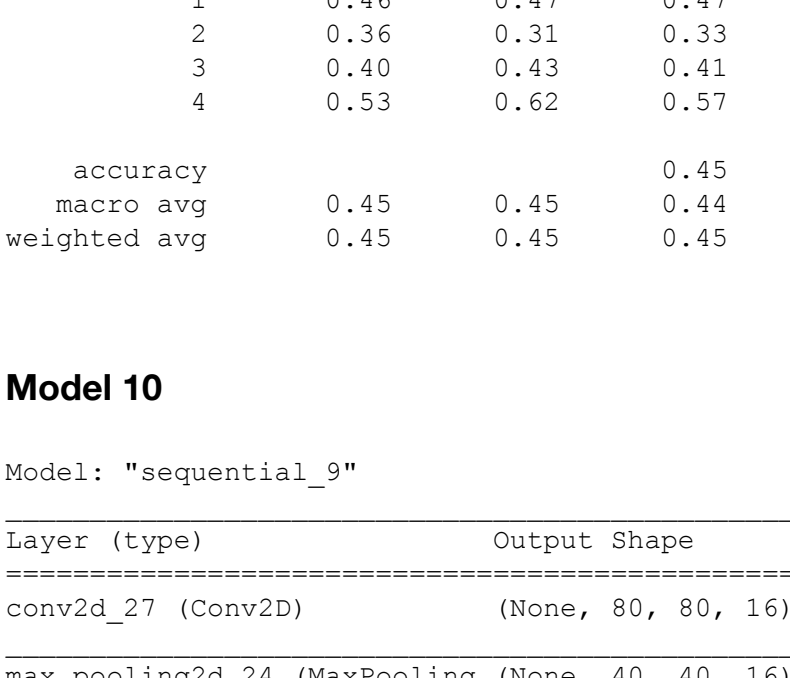

```
              precision    recall  f1-score   support

           0       0.00      0.00      0.00        82
           1       0.00      0.00      0.00        74
           2       0.00      0.00      0.00        84
           3       0.00      0.00      0.00        74
           4       0.24      1.00      0.39       100

    accuracy                           0.24       414
   macro avg       0.05      0.20      0.08       414
weighted avg       0.06      0.24      0.09       414
```

```
/usr/local/lib/python3.6/dist-packages/sklearn/metrics/_classification.py:1272: UndefinedMetricWarnin
g: Precision and F-score are ill-defined and being set to 0.0 in labels with no predicted samples. Us
e `zero_division` parameter to control this behavior.
  _warn_prf(average, modifier, msg_start, len(result))
```

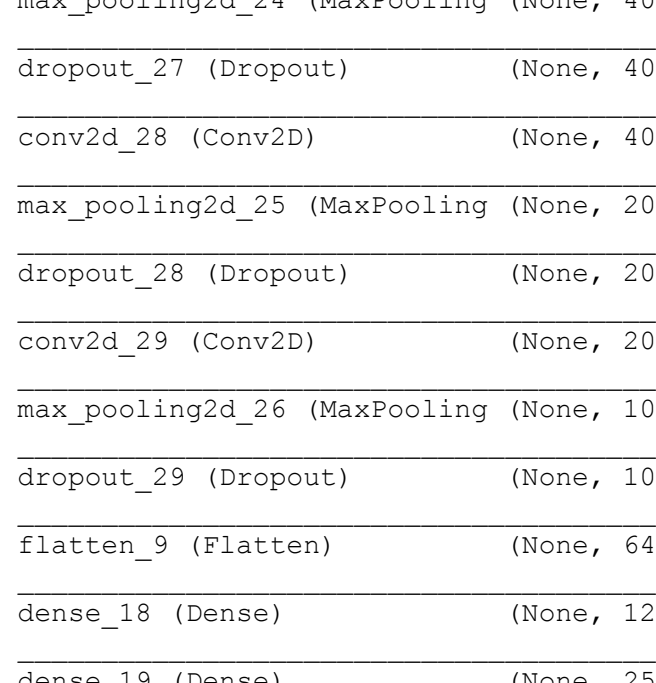
Model 9

```
Model: "sequential_8"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_24 (Conv2D)           (None, 80, 80, 16)        160
_________________________________________________________________
max_pooling2d_21 (MaxPooling (None, 40, 40, 16)        0
_________________________________________________________________
dropout_24 (Dropout)         (None, 40, 40, 16)        0
_________________________________________________________________
conv2d_25 (Conv2D)           (None, 40, 40, 32)        12832
_________________________________________________________________
max_pooling2d_22 (MaxPooling (None, 20, 20, 32)        0
_________________________________________________________________
dropout_25 (Dropout)         (None, 20, 20, 32)        0
_________________________________________________________________
conv2d_26 (Conv2D)           (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_23 (MaxPooling (None, 10, 10, 64)        0
_________________________________________________________________
dropout_26 (Dropout)         (None, 10, 10, 64)        0
_________________________________________________________________
flatten_8 (Flatten)          (None, 6400)              0
_________________________________________________________________
dense_15 (Dense)             (None, 128)               819328
_________________________________________________________________
dense_16 (Dense)             (None, 256)               33024
_________________________________________________________________
dense_17 (Dense)             (None, 5)                 1285
=================================================================
Total params: 917,893
Trainable params: 917,893
Non-trainable params: 0
_________________________________________________________________
```





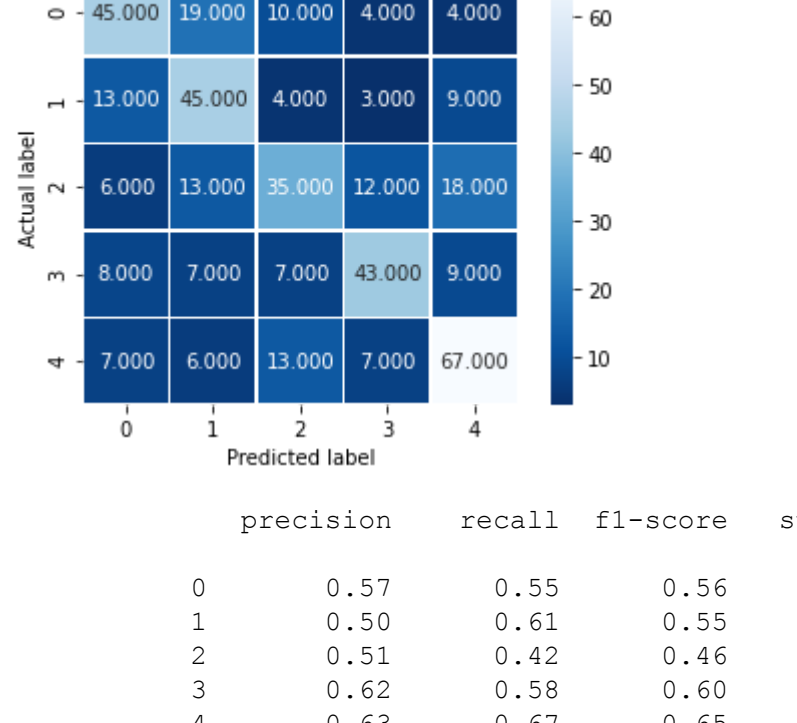

```
Maximum training accuracy:  0.9962365627288818
Maximum validation accuracy:  0.483091801404953
```

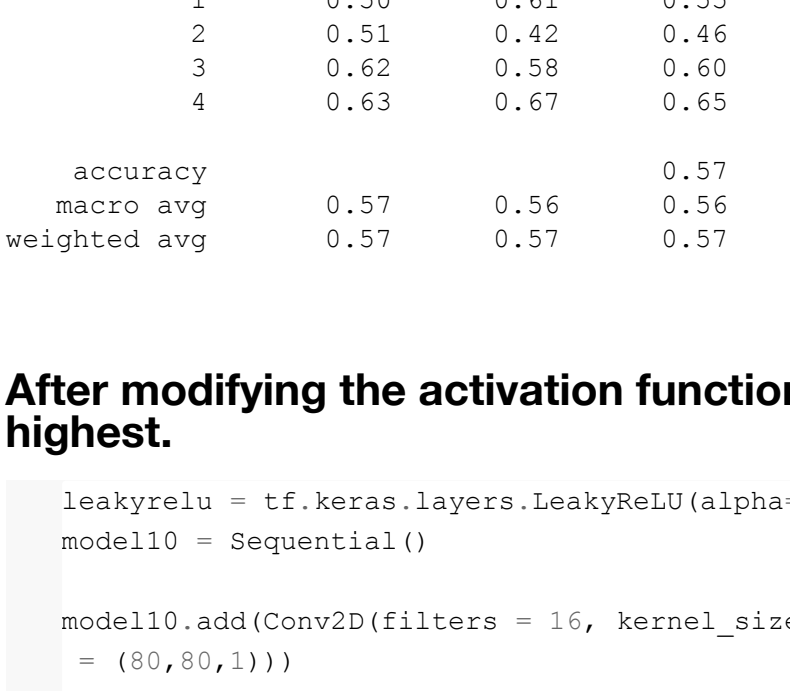



```
              precision    recall  f1-score   support

           0       0.49      0.40      0.44        82
           1       0.46      0.47      0.47        74
           2       0.36      0.31      0.33        84
           3       0.40      0.43      0.41        74
           4       0.53      0.62      0.57       100

    accuracy                           0.45       414
   macro avg       0.45      0.45      0.44       414
weighted avg       0.45      0.45      0.45       414
```

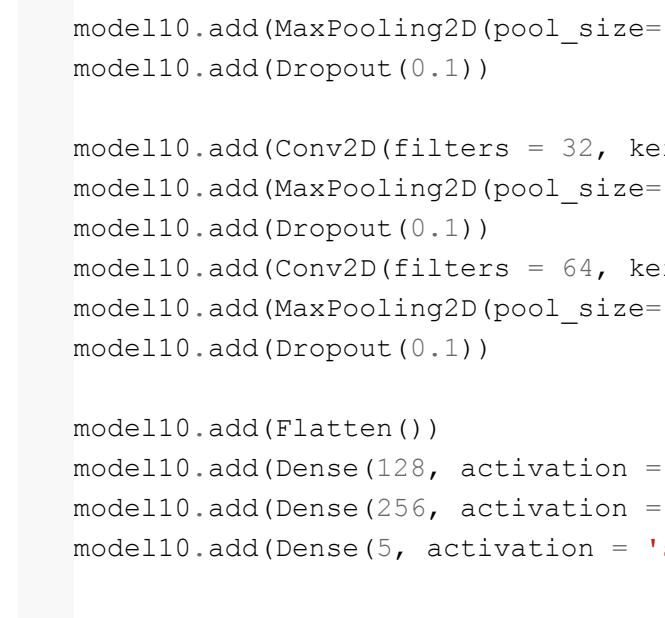
Model 10

```
Model: "sequential_9"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_27 (Conv2D)           (None, 80, 80, 16)        160
_________________________________________________________________
max_pooling2d_24 (MaxPooling (None, 40, 40, 16)        0
_________________________________________________________________
dropout_27 (Dropout)         (None, 40, 40, 16)        0
_________________________________________________________________
conv2d_28 (Conv2D)           (None, 40, 40, 32)        12832
_________________________________________________________________
max_pooling2d_25 (MaxPooling (None, 20, 20, 32)        0
_________________________________________________________________
dropout_28 (Dropout)         (None, 20, 20, 32)        0
_________________________________________________________________
conv2d_29 (Conv2D)           (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_26 (MaxPooling (None, 10, 10, 64)        0
_________________________________________________________________
dropout_29 (Dropout)         (None, 10, 10, 64)        0
_________________________________________________________________
flatten_9 (Flatten)          (None, 6400)              0
_________________________________________________________________
dense_18 (Dense)             (None, 128)               819328
_________________________________________________________________
dense_19 (Dense)             (None, 256)               33024
_________________________________________________________________
dense_20 (Dense)             (None, 5)                 1285
=================================================================
Total params: 917,893
Trainable params: 917,893
Non-trainable params: 0
_________________________________________________________________
```






```
Maximum training accuracy:  0.9981182813644409
Maximum validation accuracy:  0.5990338325500488
```




```
              precision    recall  f1-score   support

           0       0.57      0.55      0.56        82
           1       0.50      0.61      0.55        74
           2       0.51      0.42      0.46        84
           3       0.62      0.58      0.60        74
           4       0.63      0.67      0.65       100

    accuracy                           0.57       414
   macro avg       0.57      0.56      0.56       414
weighted avg       0.57      0.57      0.57       414
```

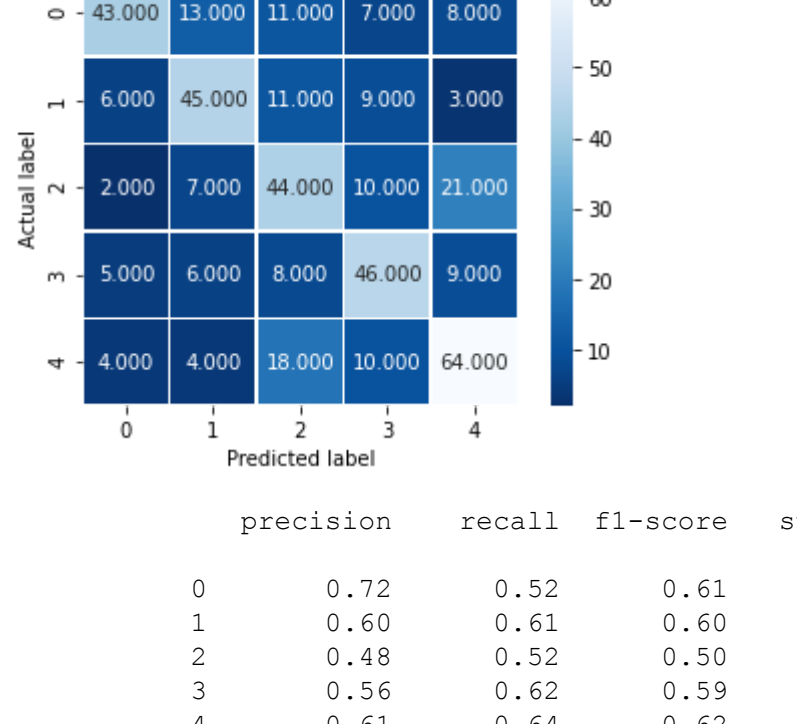
After modifying the activation functions, we see that model 10's accuracy is the highest.

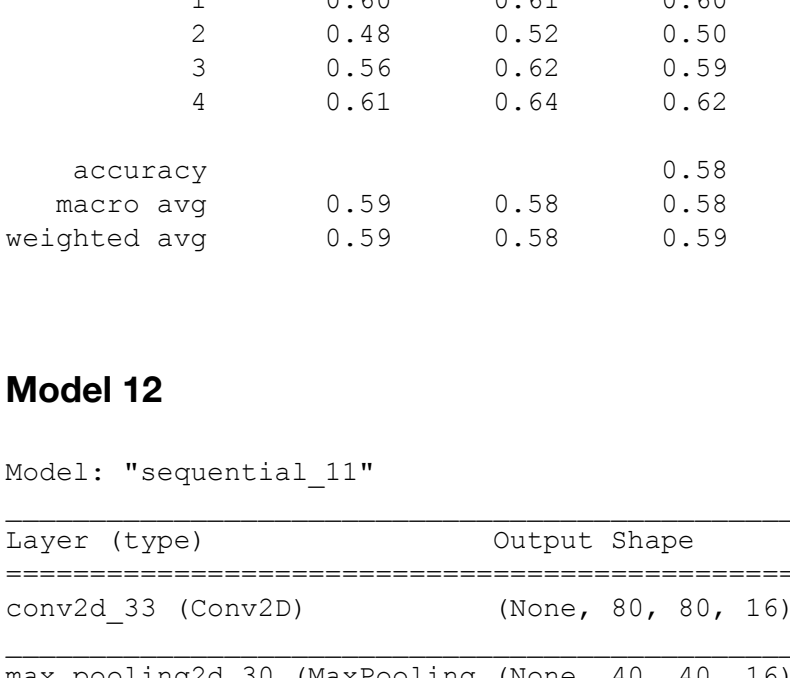
```
leakyrelu = tf.keras.layers.LeakyReLU(alpha=0.01)
model10 = Sequential()

model10.add(Conv2D(filters = 16, kernel_size = (3,3),padding = 'Same',activation = leakyrelu, input_shape
 = (80,80,1)))
model10.add(MaxPooling2D(pool_size=(2, 2)))
model10.add(Dropout(0.1))

model10.add(Conv2D(filters = 32, kernel_size = (5,5),padding = 'Same',activation = leakyrelu))
model10.add(MaxPooling2D(pool_size=(2, 2)))
model10.add(Dropout(0.1))
model10.add(Conv2D(filters = 64, kernel_size = (5,5),padding = 'Same',activation = leakyrelu))
model10.add(MaxPooling2D(pool_size=(2, 2)))
model10.add(Dropout(0.1))

model10.add(Flatten())
model10.add(Dense(128, activation = leakyrelu))
model10.add(Dense(256, activation = leakyrelu))
model10.add(Dense(5, activation = 'softmax'))

model10.compile(optimizer=Adam(),loss='categorical_crossentropy',metrics=['accuracy'])
model10.summary()
```

Thus, we will now vary the regularization parameters for model 10.

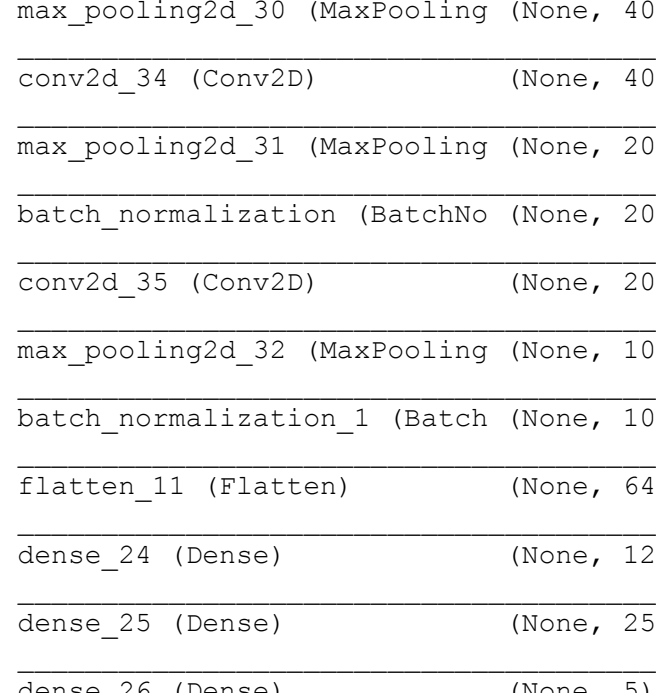
Model 11

```
Model: "sequential_10"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_30 (Conv2D)           (None, 80, 80, 16)        160
_________________________________________________________________
max_pooling2d_27 (MaxPooling (None, 40, 40, 16)        0
_________________________________________________________________
dropout_30 (Dropout)         (None, 40, 40, 16)        0
_________________________________________________________________
conv2d_31 (Conv2D)           (None, 40, 40, 32)        12832
_________________________________________________________________
max_pooling2d_28 (MaxPooling (None, 20, 20, 32)        0
_________________________________________________________________
dropout_31 (Dropout)         (None, 20, 20, 32)        0
_________________________________________________________________
conv2d_32 (Conv2D)           (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_29 (MaxPooling (None, 10, 10, 64)        0
_________________________________________________________________
dropout_32 (Dropout)         (None, 10, 10, 64)        0
_________________________________________________________________
flatten_10 (Flatten)         (None, 6400)              0
_________________________________________________________________
dense_21 (Dense)             (None, 128)               819328
_________________________________________________________________
dense_22 (Dense)             (None, 256)               33024
_________________________________________________________________
dense_23 (Dense)             (None, 5)                 1285
=================================================================
Total params: 917,893
Trainable params: 917,893
Non-trainable params: 0
_________________________________________________________________
```





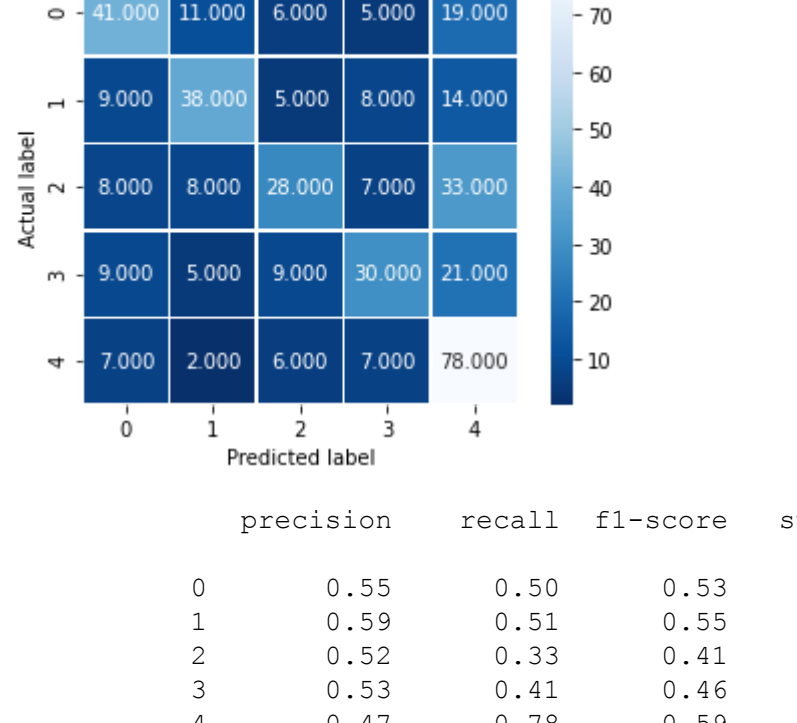

```
Maximum training accuracy:  0.9927419424057007
Maximum validation accuracy:  0.5990338325500488
```

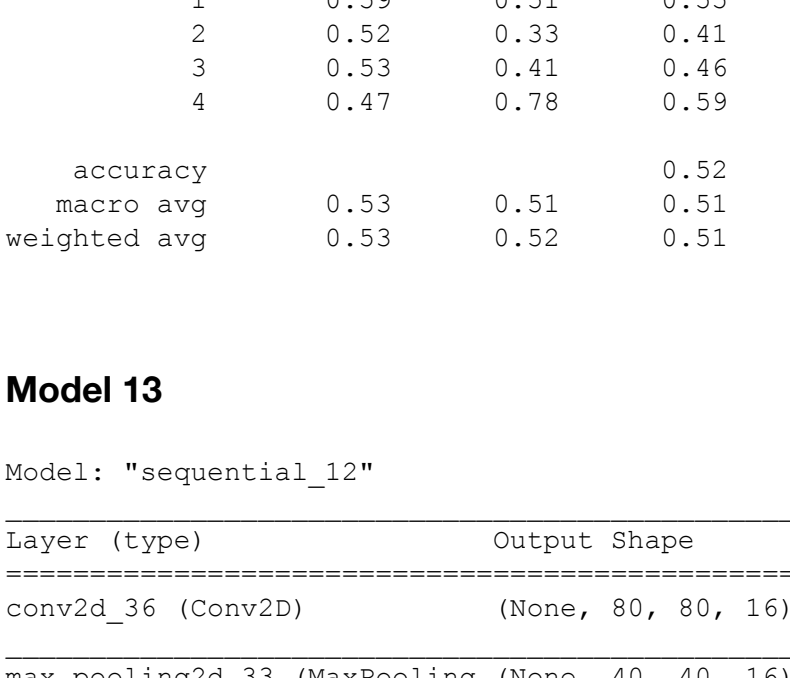



```
              precision    recall  f1-score   support

           0       0.72      0.52      0.61        82
           1       0.60      0.61      0.60        74
           2       0.48      0.52      0.50        84
           3       0.56      0.62      0.59        74
           4       0.61      0.64      0.62       100

    accuracy                           0.58       414
   macro avg       0.59      0.58      0.58       414
weighted avg       0.59      0.58      0.59       414
```

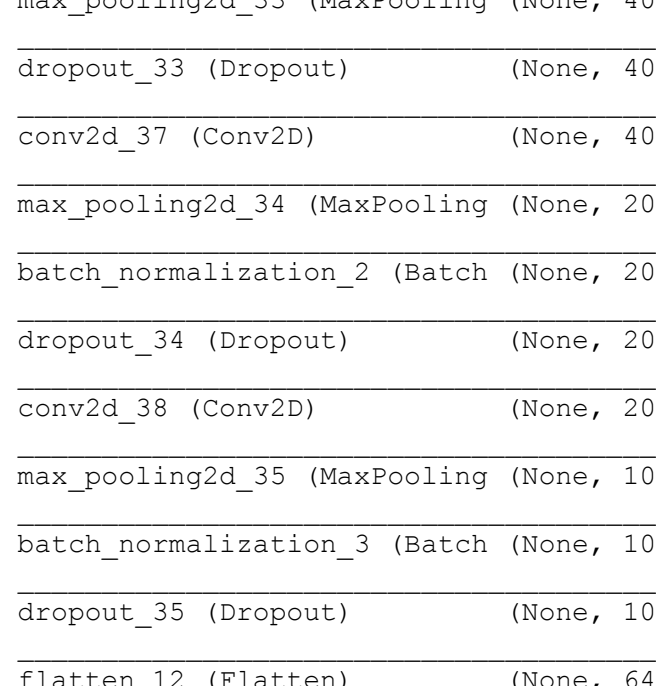
Model 12

```
Model: "sequential_11"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_33 (Conv2D)           (None, 80, 80, 16)        160
_________________________________________________________________
max_pooling2d_30 (MaxPooling (None, 40, 40, 16)        0
_________________________________________________________________
conv2d_34 (Conv2D)           (None, 40, 40, 32)        12832
_________________________________________________________________
max_pooling2d_31 (MaxPooling (None, 20, 20, 32)        0
_________________________________________________________________
batch_normalization (BatchNo (None, 20, 20, 32)        128
_________________________________________________________________
conv2d_35 (Conv2D)           (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_32 (MaxPooling (None, 10, 10, 64)        0
_________________________________________________________________
batch_normalization_1 (Batch (None, 10, 10, 64)        256
_________________________________________________________________
flatten_11 (Flatten)         (None, 6400)              0
_________________________________________________________________
dense_24 (Dense)             (None, 128)               819328
_________________________________________________________________
dense_25 (Dense)             (None, 256)               33024
_________________________________________________________________
dense_26 (Dense)             (None, 5)                 1285
=================================================================
Total params: 918,277
Trainable params: 918,085
Non-trainable params: 192
_________________________________________________________________
```





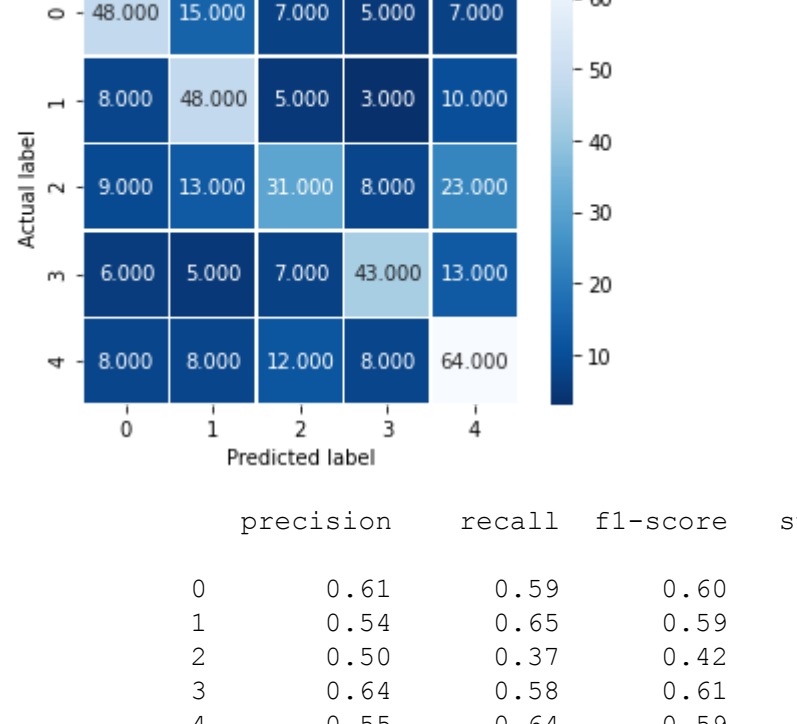

```
Maximum training accuracy:  0.998924732208252
Maximum validation accuracy:  0.5531401038169861
```

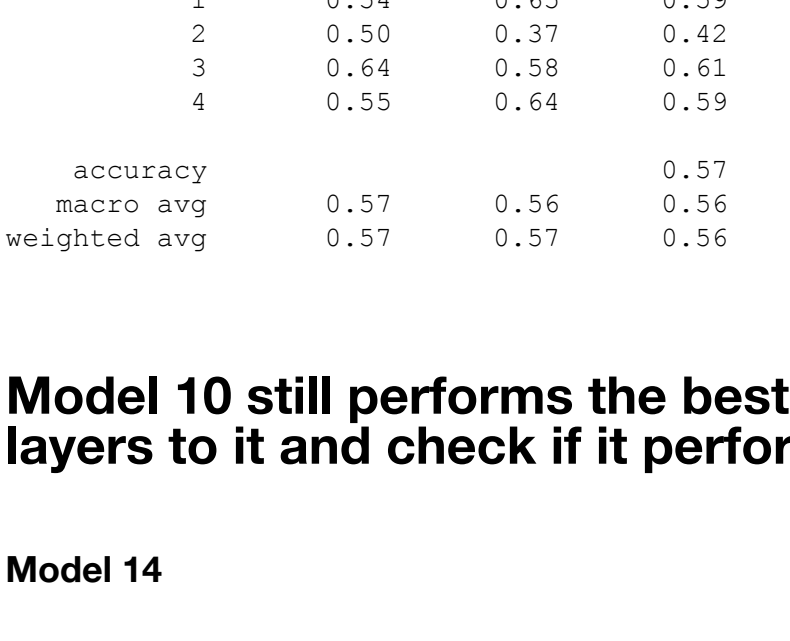



```
              precision    recall  f1-score   support

           0       0.55      0.50      0.53        82
           1       0.59      0.51      0.55        74
           2       0.52      0.33      0.41        84
           3       0.53      0.41      0.46        74
           4       0.47      0.78      0.59       100

    accuracy                           0.52       414
   macro avg       0.53      0.51      0.51       414
weighted avg       0.53      0.52      0.51       414
```

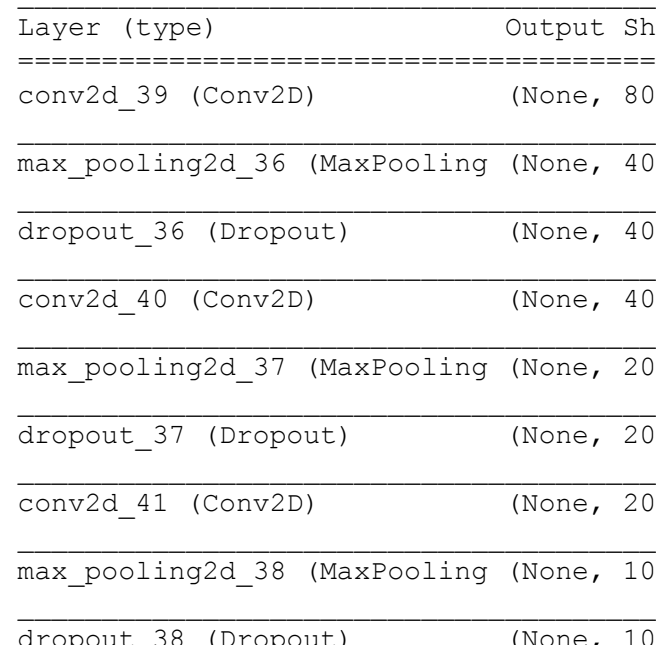
Model 13

```
Model: "sequential_12"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_36 (Conv2D)           (None, 80, 80, 16)        160
_________________________________________________________________
max_pooling2d_33 (MaxPooling (None, 40, 40, 16)        0
_________________________________________________________________
dropout_33 (Dropout)         (None, 40, 40, 16)        0
_________________________________________________________________
conv2d_37 (Conv2D)           (None, 40, 40, 32)        12832
_________________________________________________________________
max_pooling2d_34 (MaxPooling (None, 20, 20, 32)        0
_________________________________________________________________
batch_normalization_2 (Batch (None, 20, 20, 32)        128
_________________________________________________________________
dropout_34 (Dropout)         (None, 20, 20, 32)        0
_________________________________________________________________
conv2d_38 (Conv2D)           (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_35 (MaxPooling (None, 10, 10, 64)        0
_________________________________________________________________
batch_normalization_3 (Batch (None, 10, 10, 64)        256
_________________________________________________________________
dropout_35 (Dropout)         (None, 10, 10, 64)        0
_________________________________________________________________
flatten_12 (Flatten)         (None, 6400)              0
_________________________________________________________________
dense_27 (Dense)             (None, 128)               819328
_________________________________________________________________
dense_28 (Dense)             (None, 256)               33024
_________________________________________________________________
dense_29 (Dense)             (None, 5)                 1285
=================================================================
Total params: 918,277
Trainable params: 918,085
Non-trainable params: 192
_________________________________________________________________
```






```
Maximum training accuracy:  0.998924732208252
Maximum validation accuracy:  0.5845410823822021
```

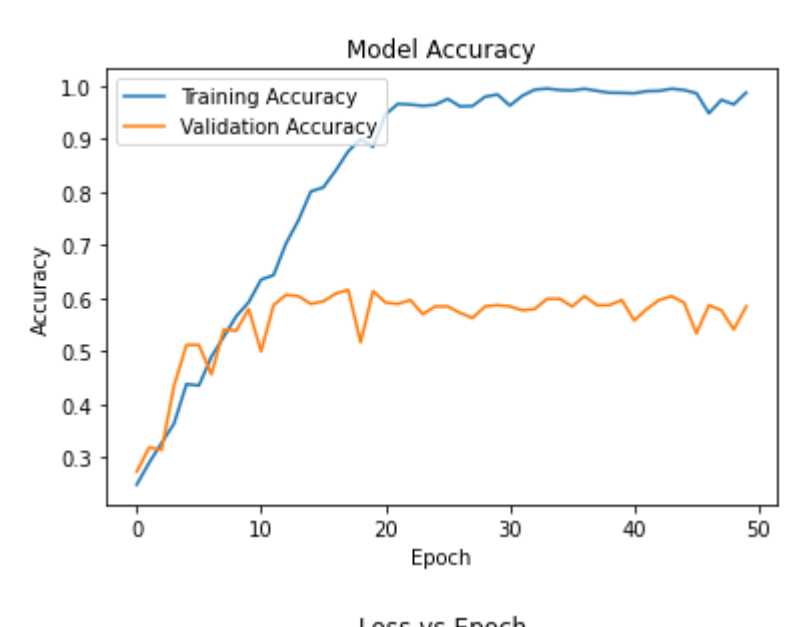


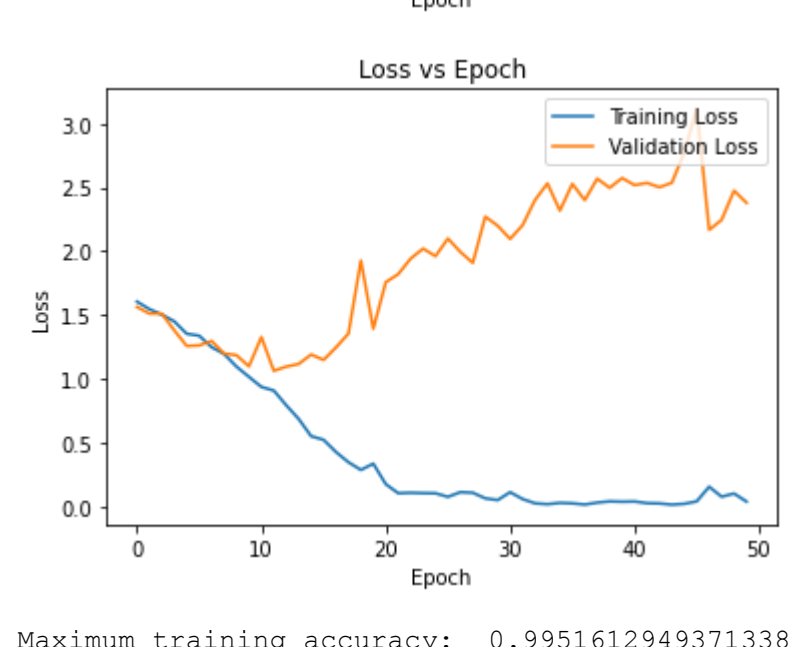

```
              precision    recall  f1-score   support

           0       0.61      0.59      0.60        82
           1       0.54      0.65      0.59        74
           2       0.50      0.37      0.42        84
           3       0.64      0.58      0.61        74
           4       0.55      0.64      0.59       100

    accuracy                           0.57       414
   macro avg       0.57      0.56      0.56       414
weighted avg       0.57      0.57      0.56       414
```

Model 10 still performs the best. Now, we will be adding more convolution layers to it and check if it performs better.

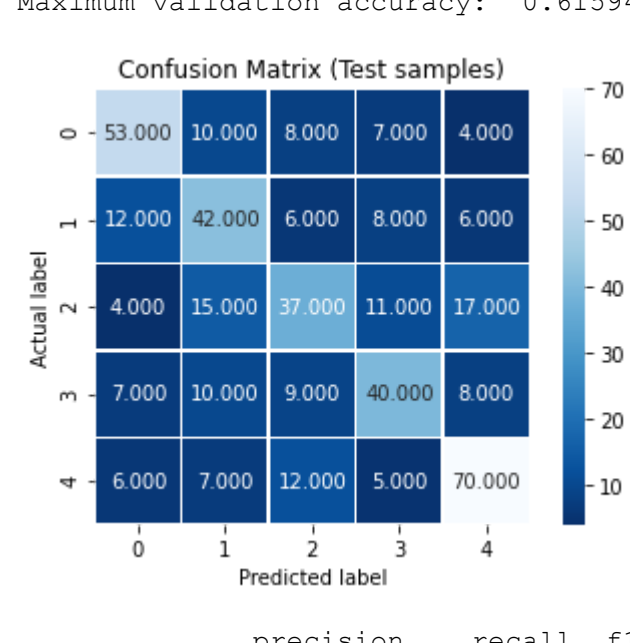
Model 14

```
Model: "sequential_13"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_39 (Conv2D)           (None, 80, 80, 16)        160
_________________________________________________________________
max_pooling2d_36 (MaxPooling (None, 40, 40, 16)        0
_________________________________________________________________
dropout_36 (Dropout)         (None, 40, 40, 16)        0
_________________________________________________________________
conv2d_40 (Conv2D)           (None, 40, 40, 32)        12832
_________________________________________________________________
max_pooling2d_37 (MaxPooling (None, 20, 20, 32)        0
_________________________________________________________________
dropout_37 (Dropout)         (None, 20, 20, 32)        0
_________________________________________________________________
conv2d_41 (Conv2D)           (None, 20, 20, 64)        51264
_________________________________________________________________
max_pooling2d_38 (MaxPooling (None, 10, 10, 64)        0
_________________________________________________________________
dropout_38 (Dropout)         (None, 10, 10, 64)        0
_________________________________________________________________
conv2d_42 (Conv2D)           (None, 10, 10, 128)       204928
_________________________________________________________________
max_pooling2d_39 (MaxPooling (None, 5, 5, 128)         0
_________________________________________________________________
dropout_39 (Dropout)         (None, 5, 5, 128)         0
_________________________________________________________________
flatten_13 (Flatten)         (None, 3200)              0
_________________________________________________________________
dense_30 (Dense)             (None, 128)               409728
_________________________________________________________________
dense_31 (Dense)             (None, 256)               33024
_________________________________________________________________
dense_32 (Dense)             (None, 5)                 1285
=================================================================
Total params: 713,221
Trainable params: 713,221
Non-trainable params: 0
_________________________________________________________________
```





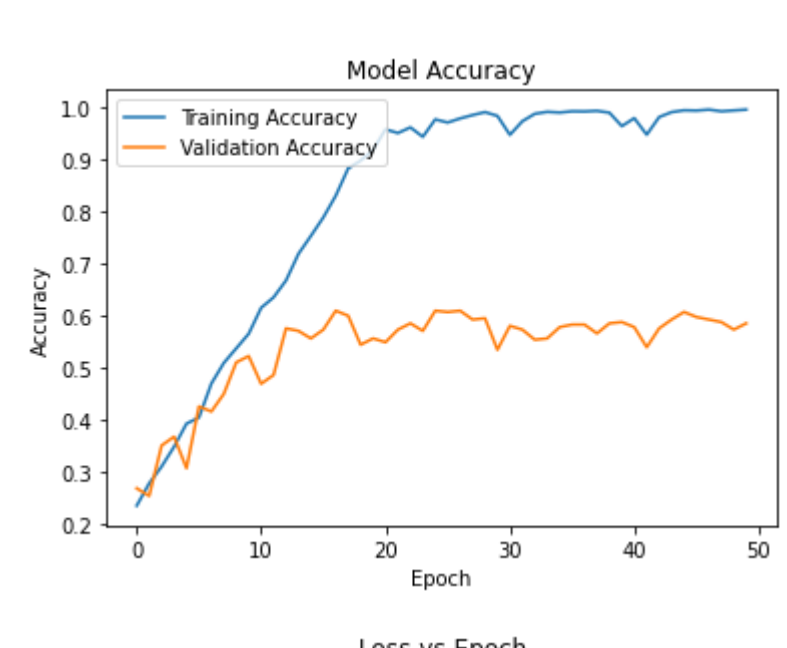
```
Maximum training accuracy:  0.9951612949371338
Maximum validation accuracy:  0.6159420013427734
```

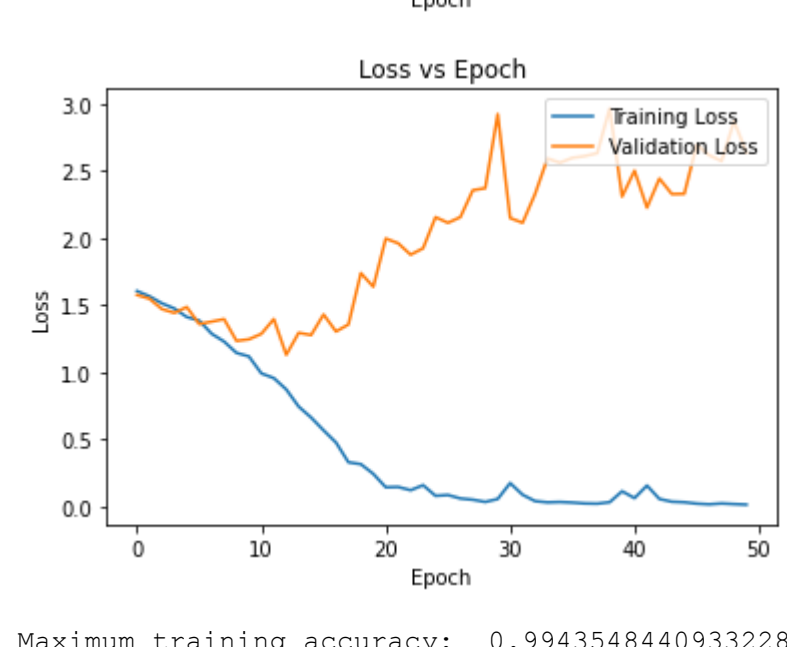


```
              precision    recall  f1-score   support

           0       0.65      0.65      0.65        82
           1       0.50      0.57      0.53        74
           2       0.51      0.44      0.47        84
           3       0.56      0.54      0.55        74
           4       0.67      0.70      0.68       100

    accuracy                           0.58       414
   macro avg       0.58      0.58      0.58       414
weighted avg       0.58      0.58      0.58       414
```

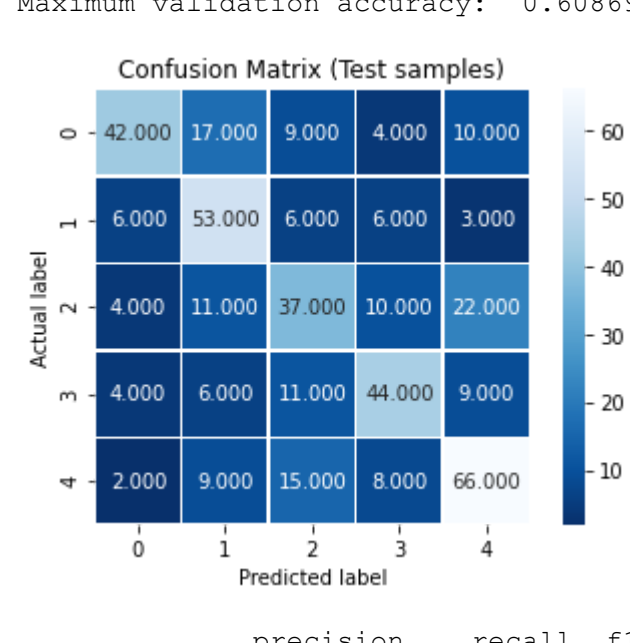
Model 15

```
Model: "sequential_14"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_43 (Conv2D)           (None, 80, 80, 16)        160       
_________________________________________________________________
max_pooling2d_40 (MaxPooling (None, 40, 40, 16)        0         
_________________________________________________________________
dropout_40 (Dropout)         (None, 40, 40, 16)        0         
_________________________________________________________________
conv2d_44 (Conv2D)           (None, 40, 40, 32)        12832     
_________________________________________________________________
max_pooling2d_41 (MaxPooling (None, 20, 20, 32)        0         
_________________________________________________________________
dropout_41 (Dropout)         (None, 20, 20, 32)        0         
_________________________________________________________________
conv2d_45 (Conv2D)           (None, 20, 20, 64)        51264     
_________________________________________________________________
max_pooling2d_42 (MaxPooling (None, 10, 10, 64)        0         
_________________________________________________________________
dropout_42 (Dropout)         (None, 10, 10, 64)        0         
_________________________________________________________________
conv2d_46 (Conv2D)           (None, 10, 10, 128)       204928    
_________________________________________________________________
max_pooling2d_43 (MaxPooling (None, 5, 5, 128)         0         
_________________________________________________________________
dropout_43 (Dropout)         (None, 5, 5, 128)         0         
_________________________________________________________________
conv2d_47 (Conv2D)           (None, 5, 5, 256)         819456    
_________________________________________________________________
max_pooling2d_44 (MaxPooling (None, 2, 2, 256)         0         
_________________________________________________________________
dropout_44 (Dropout)         (None, 2, 2, 256)         0         
_________________________________________________________________
flatten_14 (Flatten)         (None, 1024)              0         
_________________________________________________________________
dense_33 (Dense)             (None, 128)               131200    
_________________________________________________________________
dense_34 (Dense)             (None, 256)               33024     
_________________________________________________________________
dense_35 (Dense)             (None, 5)                 1285      
=================================================================
Total params: 1,254,149
Trainable params: 1,254,149
Non-trainable params: 0
_________________________________________________________________
```





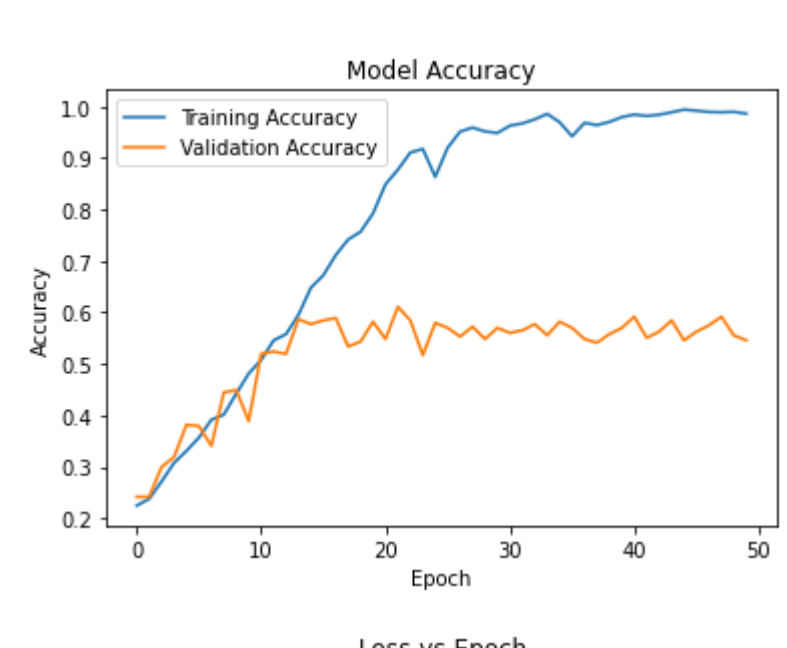
```
Maximum training accuracy:  0.9943548440933228
Maximum validation accuracy:  0.6086956262588501
```

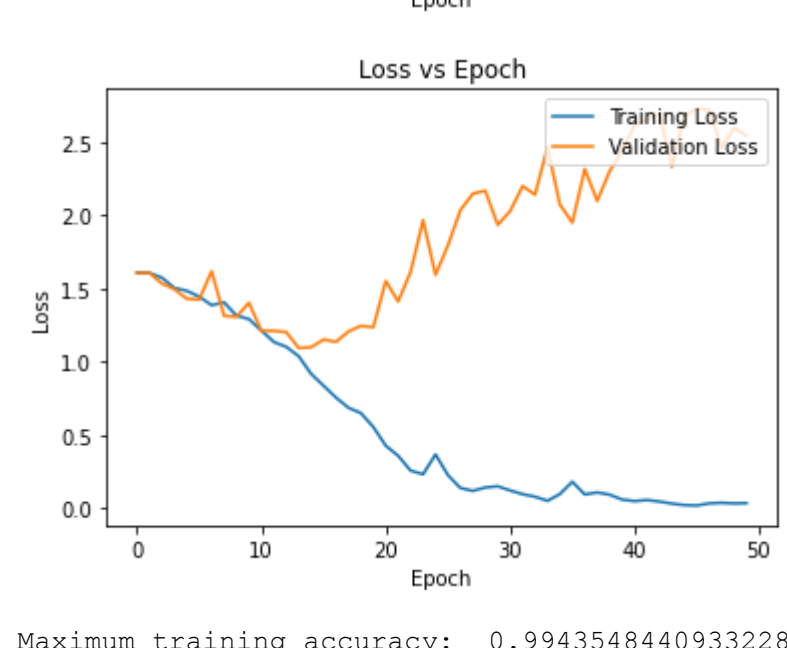


```
              precision    recall  f1-score   support

           0       0.72      0.51      0.60        82
           1       0.55      0.72      0.62        74
           2       0.47      0.44      0.46        84
           3       0.61      0.59      0.60        74
           4       0.60      0.66      0.63       100

    accuracy                           0.58       414
   macro avg       0.59      0.58      0.58       414
weighted avg       0.59      0.58      0.58       414
```

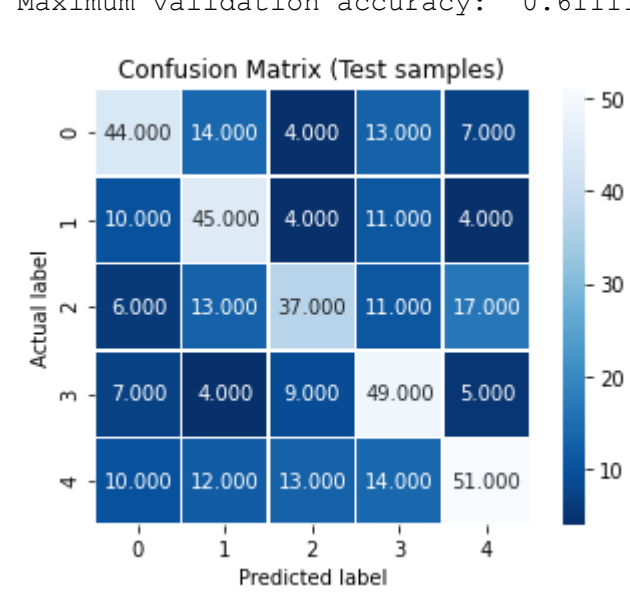
Model 16

```
Model: "sequential_15"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_48 (Conv2D)           (None, 80, 80, 16)        160       
_________________________________________________________________
max_pooling2d_45 (MaxPooling (None, 40, 40, 16)        0         
_________________________________________________________________
dropout_45 (Dropout)         (None, 40, 40, 16)        0         
_________________________________________________________________
conv2d_49 (Conv2D)           (None, 40, 40, 32)        12832     
_________________________________________________________________
max_pooling2d_46 (MaxPooling (None, 20, 20, 32)        0         
_________________________________________________________________
dropout_46 (Dropout)         (None, 20, 20, 32)        0         
_________________________________________________________________
conv2d_50 (Conv2D)           (None, 20, 20, 64)        51264     
_________________________________________________________________
max_pooling2d_47 (MaxPooling (None, 10, 10, 64)        0         
_________________________________________________________________
dropout_47 (Dropout)         (None, 10, 10, 64)        0         
_________________________________________________________________
conv2d_51 (Conv2D)           (None, 10, 10, 128)       204928    
_________________________________________________________________
max_pooling2d_48 (MaxPooling (None, 5, 5, 128)         0         
_________________________________________________________________
dropout_48 (Dropout)         (None, 5, 5, 128)         0         
_________________________________________________________________
conv2d_52 (Conv2D)           (None, 5, 5, 256)         819456    
_________________________________________________________________
max_pooling2d_49 (MaxPooling (None, 2, 2, 256)         0         
_________________________________________________________________
dropout_49 (Dropout)         (None, 2, 2, 256)         0         
_________________________________________________________________
conv2d_53 (Conv2D)           (None, 2, 2, 512)         3277312   
_________________________________________________________________
max_pooling2d_50 (MaxPooling (None, 1, 1, 512)         0         
_________________________________________________________________
dropout_50 (Dropout)         (None, 1, 1, 512)         0         
_________________________________________________________________
flatten_15 (Flatten)         (None, 512)               0         
_________________________________________________________________
dense_36 (Dense)             (None, 128)               65664     
_________________________________________________________________
dense_37 (Dense)             (None, 256)               33024     
_________________________________________________________________
dense_38 (Dense)             (None, 5)                 1285      
=================================================================
Total params: 4,465,925
Trainable params: 4,465,925
Non-trainable params: 0
_________________________________________________________________
```





```
Maximum training accuracy:  0.9943548440933228
Maximum validation accuracy:  0.6111111044883728
```



```
              precision    recall  f1-score   support

           0       0.57      0.54      0.55        82
           1       0.51      0.61      0.56        74
           2       0.55      0.44      0.49        84
           3       0.50      0.66      0.57        74
           4       0.61      0.51      0.55       100

    accuracy                           0.55       414
   macro avg       0.55      0.55      0.54       414
weighted avg       0.55      0.55      0.54       414
```

Model 16 is hence the best model so far with an accuracy of 63.87% on the validation dataset.

```
leakyrelu = tf.keras.layers.LeakyReLU(alpha=0.01)
model16 = Sequential()

model16.add(Conv2D(filters = 16, kernel_size = (3,3),padding = 'Same',activation = leakyrelu, input_shape
 = (80,80,1)))
model16.add(MaxPooling2D(pool_size=(2, 2)))
model16.add(Dropout(0.1))

model16.add(Conv2D(filters = 32, kernel_size = (5,5),padding = 'Same',activation = leakyrelu))
model16.add(MaxPooling2D(pool_size=(2, 2)))
model16.add(Dropout(0.1))

model16.add(Conv2D(filters = 64, kernel_size = (5,5),padding = 'Same',activation = leakyrelu))
model16.add(MaxPooling2D(pool_size=(2, 2)))
model16.add(Dropout(0.1))

model16.add(Conv2D(filters = 128, kernel_size = (5,5),padding = 'Same',activation = leakyrelu))
model16.add(MaxPooling2D(pool_size=(2, 2)))
model16.add(Dropout(0.1))

model16.add(Conv2D(filters = 256, kernel_size = (5,5),padding = 'Same',activation = leakyrelu))
model16.add(MaxPooling2D(pool_size=(2, 2)))
model16.add(Dropout(0.1))

model16.add(Conv2D(filters = 512, kernel_size = (5,5),padding = 'Same',activation = leakyrelu))
model16.add(MaxPooling2D(pool_size=(2, 2)))
model16.add(Dropout(0.1))

model16.add(Flatten())
model16.add(Dense(128, activation = leakyrelu))
model16.add(Dense(256, activation = leakyrelu))
model16.add(Dense(5, activation = 'softmax'))

model16.compile(optimizer=Adam(),loss='categorical_crossentropy',metrics=['accuracy'])
model16.summary()
```

Now, we will use this model and run the experiment on color images.

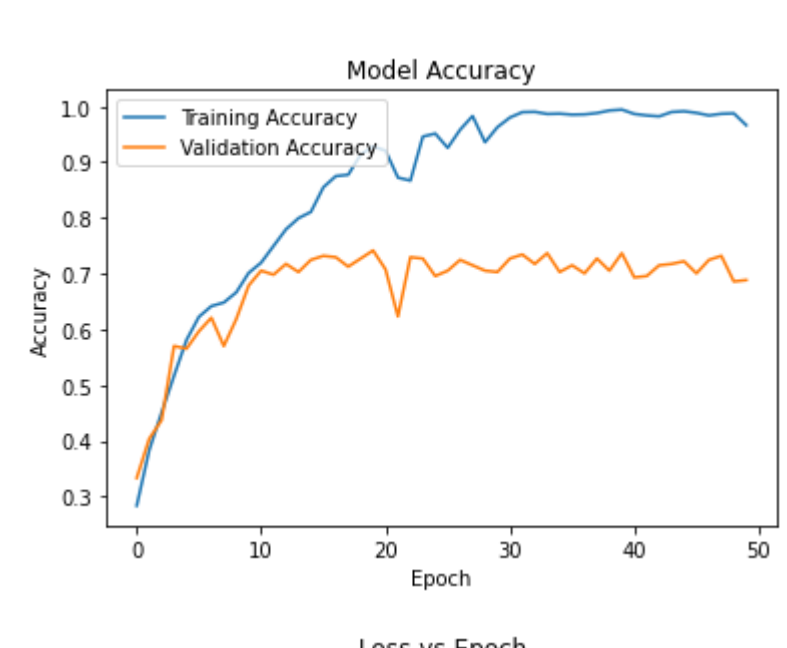
Load the colour dataset

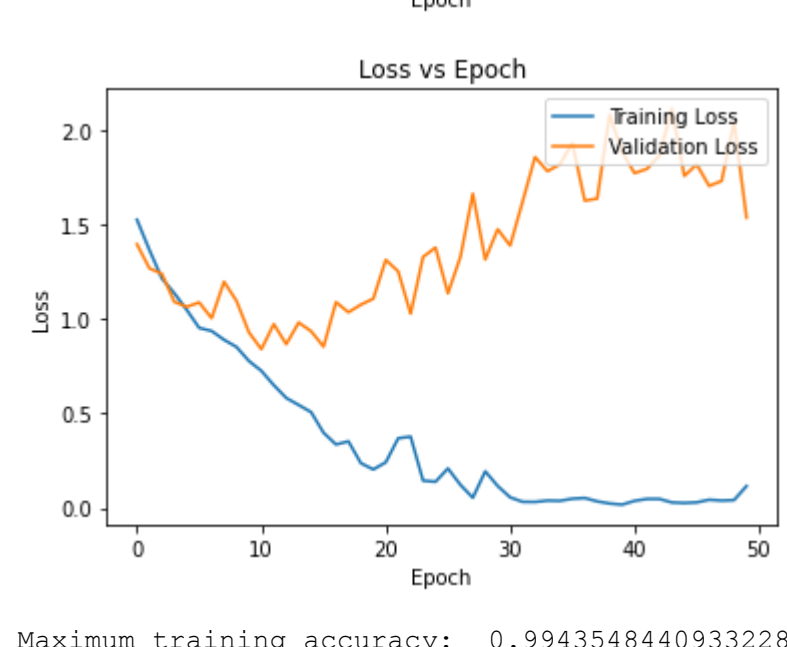
Pre-processing

Train : Test split

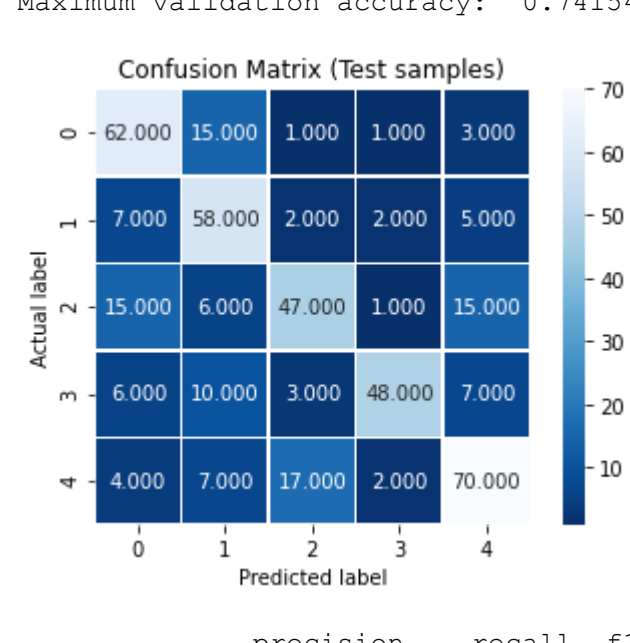
Training the model

```
Model: "sequential_16"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_54 (Conv2D)           (None, 80, 80, 16)        448       
_________________________________________________________________
max_pooling2d_51 (MaxPooling (None, 40, 40, 16)        0         
_________________________________________________________________
dropout_51 (Dropout)         (None, 40, 40, 16)        0         
_________________________________________________________________
conv2d_55 (Conv2D)           (None, 40, 40, 32)        12832     
_________________________________________________________________
max_pooling2d_52 (MaxPooling (None, 20, 20, 32)        0         
_________________________________________________________________
dropout_52 (Dropout)         (None, 20, 20, 32)        0         
_________________________________________________________________
conv2d_56 (Conv2D)           (None, 20, 20, 64)        51264     
_________________________________________________________________
max_pooling2d_53 (MaxPooling (None, 10, 10, 64)        0         
_________________________________________________________________
dropout_53 (Dropout)         (None, 10, 10, 64)        0         
_________________________________________________________________
conv2d_57 (Conv2D)           (None, 10, 10, 128)       204928    
_________________________________________________________________
max_pooling2d_54 (MaxPooling (None, 5, 5, 128)         0         
_________________________________________________________________
dropout_54 (Dropout)         (None, 5, 5, 128)         0         
_________________________________________________________________
conv2d_58 (Conv2D)           (None, 5, 5, 256)         819456    
_________________________________________________________________
max_pooling2d_55 (MaxPooling (None, 2, 2, 256)         0         
_________________________________________________________________
dropout_55 (Dropout)         (None, 2, 2, 256)         0         
_________________________________________________________________
conv2d_59 (Conv2D)           (None, 2, 2, 512)         3277312   
_________________________________________________________________
max_pooling2d_56 (MaxPooling (None, 1, 1, 512)         0         
_________________________________________________________________
dropout_56 (Dropout)         (None, 1, 1, 512)         0         
_________________________________________________________________
flatten_16 (Flatten)         (None, 512)               0         
_________________________________________________________________
dense_39 (Dense)             (None, 128)               65664     
_________________________________________________________________
dense_40 (Dense)             (None, 256)               33024     
_________________________________________________________________
dense_41 (Dense)             (None, 5)                 1285      
=================================================================
Total params: 4,466,213
Trainable params: 4,466,213
Non-trainable params: 0
_________________________________________________________________
```



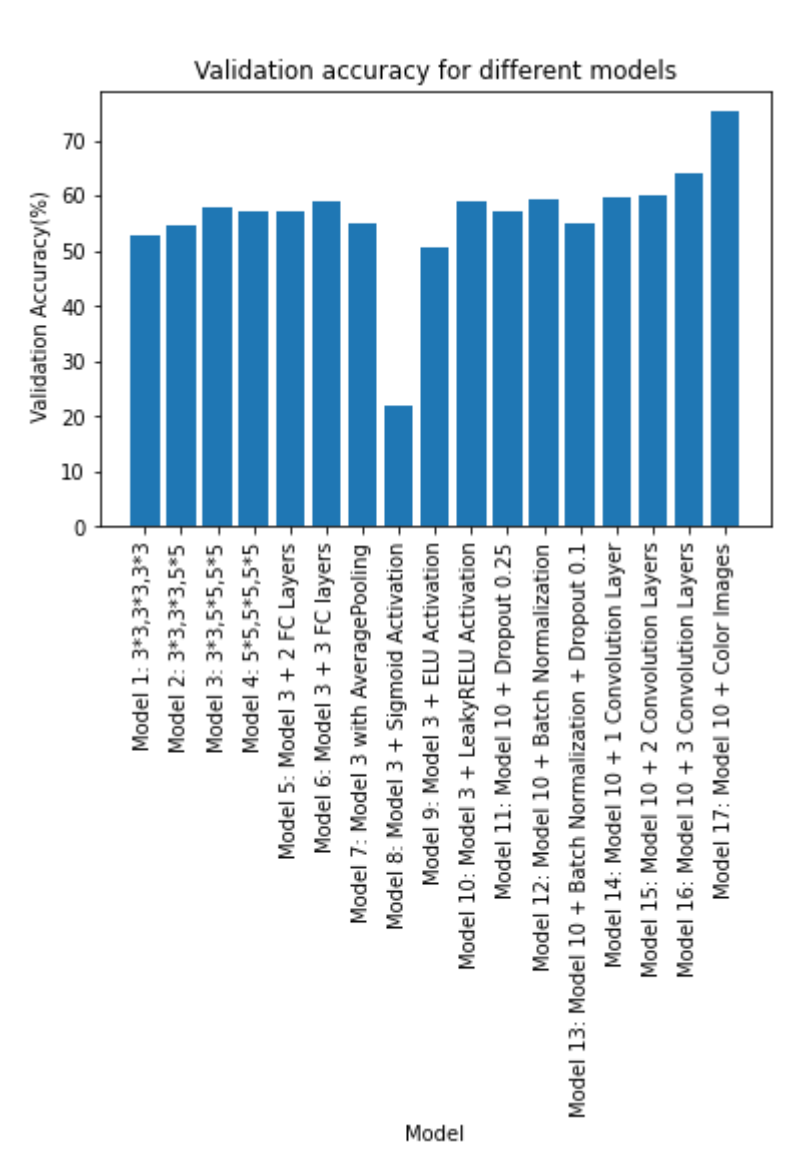


```
Maximum training accuracy:  0.9943548440933228
Maximum validation accuracy:  0.7415459156036377
```



```
              precision    recall  f1-score   support

           0       0.66      0.76      0.70        82
           1       0.60      0.78      0.68        74
           2       0.67      0.56      0.61        84
           3       0.89      0.65      0.75        74
           4       0.70      0.70      0.70       100

    accuracy                           0.69       414
   macro avg       0.70      0.69      0.69       414
weighted avg       0.70      0.69      0.69       414
```

Plot bar-graph for comparing validation accuracy for all the models



Trying out the best model on MNIST Dataset

Loading Dataset

Preparing the images for feeding into CNN

Categorical (One-hot) Encoding

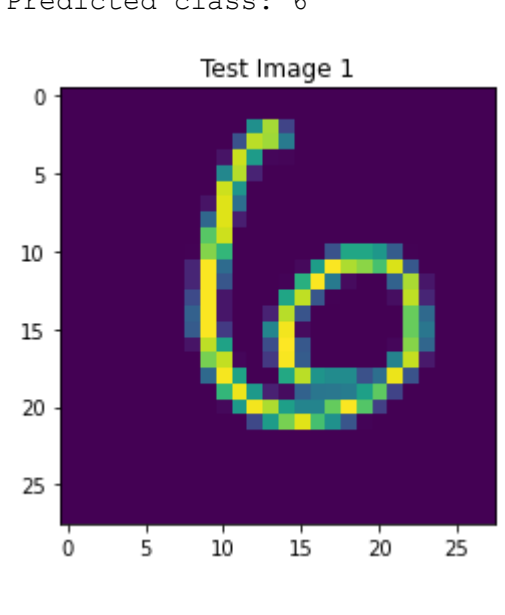
Model

```
Model: "sequential_17"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_60 (Conv2D)           (None, 28, 28, 16)        160       
_________________________________________________________________
max_pooling2d_57 (MaxPooling (None, 14, 14, 16)        0         
_________________________________________________________________
dropout_57 (Dropout)         (None, 14, 14, 16)        0         
_________________________________________________________________
conv2d_61 (Conv2D)           (None, 14, 14, 32)        12832     
_________________________________________________________________
max_pooling2d_58 (MaxPooling (None, 7, 7, 32)          0         
_________________________________________________________________
dropout_58 (Dropout)         (None, 7, 7, 32)          0         
_________________________________________________________________
conv2d_62 (Conv2D)           (None, 7, 7, 64)          51264     
_________________________________________________________________
max_pooling2d_59 (MaxPooling (None, 3, 3, 64)          0         
_________________________________________________________________
dropout_59 (Dropout)         (None, 3, 3, 64)          0         
_________________________________________________________________
conv2d_63 (Conv2D)           (None, 3, 3, 128)         204928    
_________________________________________________________________
max_pooling2d_60 (MaxPooling (None, 1, 1, 128)         0         
_________________________________________________________________
dropout_60 (Dropout)         (None, 1, 1, 128)         0         
_________________________________________________________________
conv2d_64 (Conv2D)           (None, 1, 1, 256)         819456    
_________________________________________________________________
dropout_61 (Dropout)         (None, 1, 1, 256)         0         
_________________________________________________________________
conv2d_65 (Conv2D)           (None, 1, 1, 512)         3277312   
_________________________________________________________________
dropout_62 (Dropout)         (None, 1, 1, 512)         0         
_________________________________________________________________
flatten_17 (Flatten)         (None, 512)               0         
_________________________________________________________________
dense_42 (Dense)             (None, 128)               65664     
_________________________________________________________________
dense_43 (Dense)             (None, 256)               33024     
_________________________________________________________________
dense_44 (Dense)             (None, 10)                2570      
=================================================================
Total params: 4,467,210
Trainable params: 4,467,210
Non-trainable params: 0
_________________________________________________________________
```

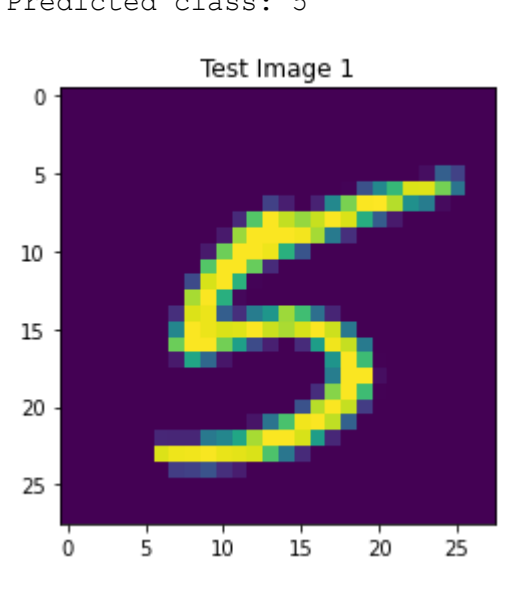
```
Epoch 1/10
422/422 [==============================] - 7s 16ms/step - loss: 0.3477 - accuracy: 0.8831 - val_loss: 0.0603 - val_accuracy: 0.9820
Epoch 2/10
422/422 [==============================] - 6s 15ms/step - loss: 0.0841 - accuracy: 0.9770 - val_loss: 0.0636 - val_accuracy: 0.9822
Epoch 3/10
422/422 [==============================] - 6s 15ms/step - loss: 0.0660 - accuracy: 0.9825 - val_loss: 0.0543 - val_accuracy: 0.9892
Epoch 4/10
422/422 [==============================] - 6s 15ms/step - loss: 0.0562 - accuracy: 0.9849 - val_loss: 0.0412 - val_accuracy: 0.9902
Epoch 5/10
422/422 [==============================] - 6s 15ms/step - loss: 0.0506 - accuracy: 0.9869 - val_loss: 0.0368 - val_accuracy: 0.9923
Epoch 6/10
422/422 [==============================] - 6s 15ms/step - loss: 0.0428 - accuracy: 0.9883 - val_loss: 0.0453 - val_accuracy: 0.9892
Epoch 7/10
422/422 [==============================] - 6s 15ms/step - loss: 0.0404 - accuracy: 0.9897 - val_loss: 0.0380 - val_accuracy: 0.9917
Epoch 8/10
422/422 [==============================] - 6s 15ms/step - loss: 0.0390 - accuracy: 0.9900 - val_loss: 0.0373 - val_accuracy: 0.9917
Epoch 9/10
422/422 [==============================] - 6s 15ms/step - loss: 0.0336 - accuracy: 0.9911 - val_loss: 0.0390 - val_accuracy: 0.9912
Epoch 10/10
422/422 [==============================] - 6s 15ms/step - loss: 0.0310 - accuracy: 0.9921 - val_loss: 0.0393 - val_accuracy: 0.9917
```

Making predictions on 5 test images

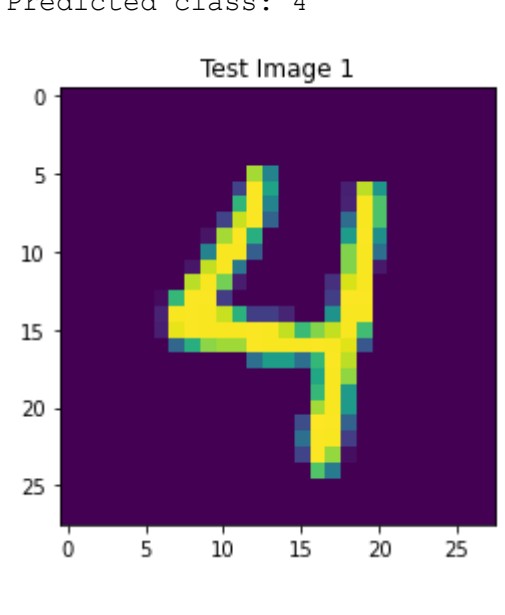
```
True class: 6
Predicted class: 6
```



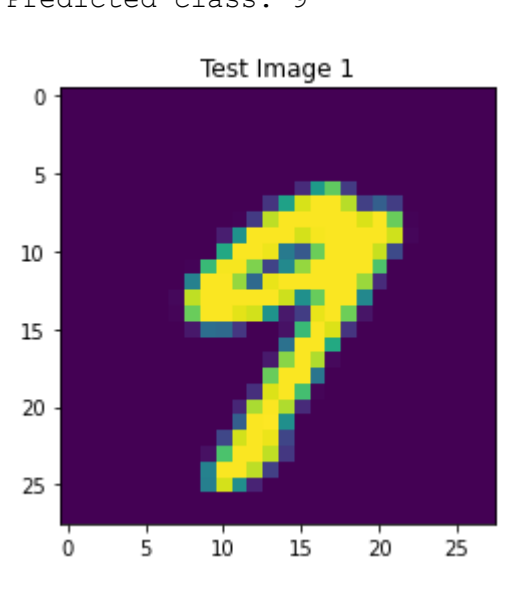
```
True class: 5
Predicted class: 5
```



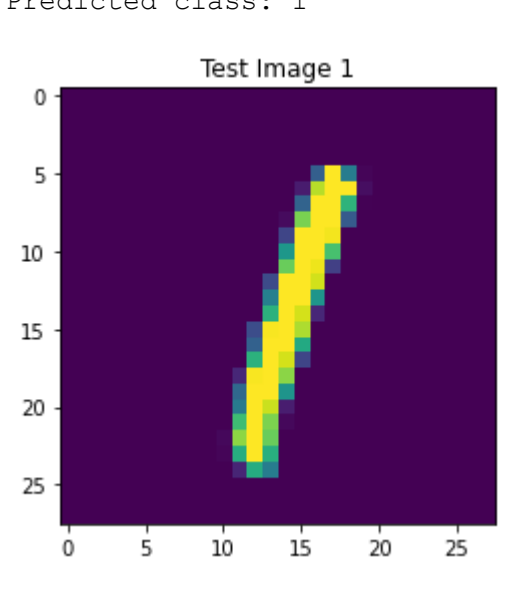
```
True class: 4
Predicted class: 4
```



```
True class: 9
Predicted class: 9
```

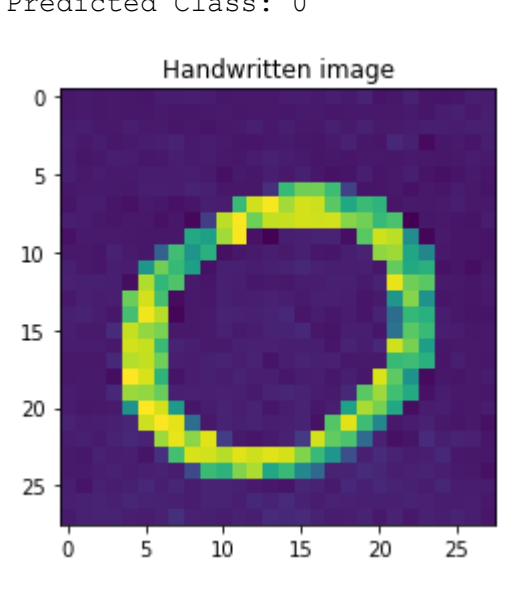


```
True class: 1
Predicted class: 1
```

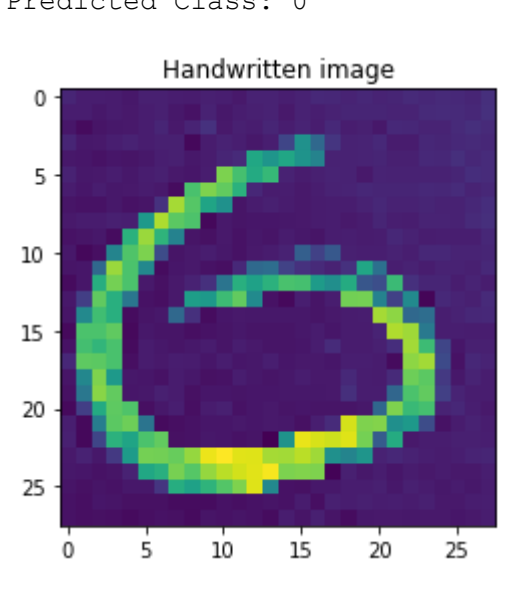


Testing on 5 handwritten images

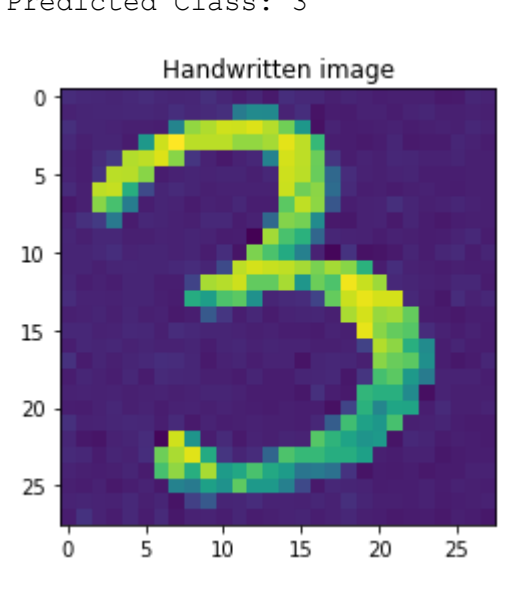
```
Predicted Class: 0
```



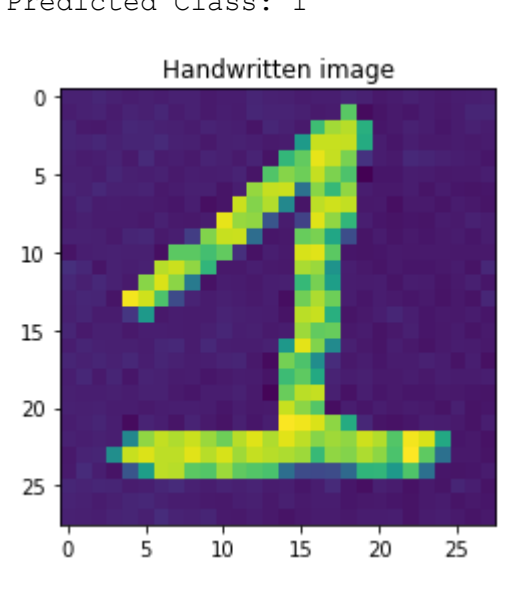
```
Predicted Class: 0
```



```
Predicted Class: 3
```



```
Predicted Class: 1
```



```
Predicted Class: 2
```