Homework-3

CSCE 633: Machine Learning

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Introduction:

In this HW, we looked at the use of Artificial Neural Networks to perform image recognition.
The dataset consists of labelled images of humans depicting different facial expression. The recgonition task was to accurately discern the facial expression being depicted in the image.

The dataset was consisted of several 48X48 grayscale images. i.e. each image was considered as a vector of length 2304, with each element representing the intensity of that pixel.

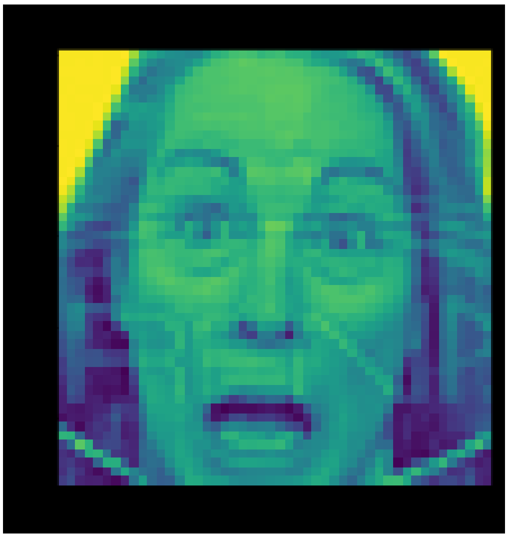
We look at two main approaches here

1. The use of a Feed Forward Network
2. Use of a Convolutional Neural Network.

While these are the two broad approaches in this study, each method had their own nuances and required careful manipulation of hyperparameters.

Data Exploration:

In this part, we explored the data that we were going to model. The first step was to plot the images from the data that we had. This was done using inbuilt functions in python.


(one such example) more in the code section.

We also looked at how many exhibits from each of the labels were present in the training dataset.

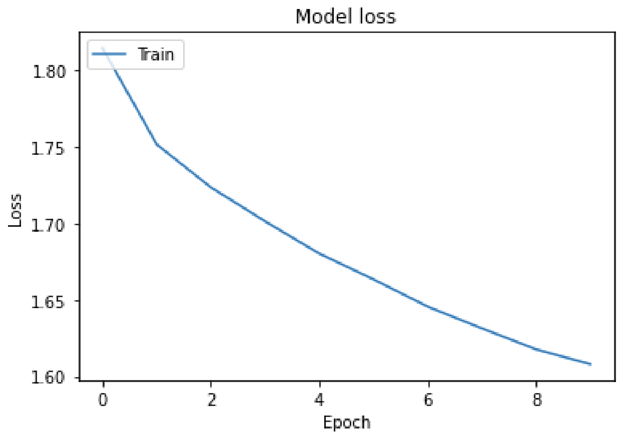
```
Angry:    3995
Disgust:   436
Fear:     4097
Happy:    7215
Sad:      4830
Surprise: 3171
Neutral:  4965
_______
Total:   28709
```

Feedforward Neural Network:

In this section we construct a FNN using the keras library and test the performance of the model with the validation data by playing around with hyperparameter values. I liked the hyperopt library, so I used this to find optimal hyperparameter values. My search space consisted of the following parameters:

```
space = {
    # The activation_fn choices:
    'activation_fn':hp.choice('activation_fn',['relu']),
    # Uniform distribution in finding appropriate dropout values
    'dropout_prob': hp.uniform('dropout_prob', 0.1, 0.5),
    # Choice of optimizer
    'optimizer': hp.choice('optimizer', ['Adam', 'sgd']),
}
```

We also plotted the loss as a function of the number of iterations (epochs?). One such example is show below. The rest are shown as a part of the code section.



Some stats that are printed with every change in hyperparameters: (This was done using Prafulla's code)

```
Total Training Time is (s):
7.4364213943481445
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.25336800158266903, 'optimizer': 'sgd'}
Accuracy:
0.39091668988991396
----------------------------------------------------
  4%|▌          | 1/25 [00:07<03:11,  8.00s/it, best loss: -0.39091668988991396]
                          Model loss
```

The best hyperparams were then used and the model was tested on the test set.

```
=======================================================================
Best Hyperparameters {'activation_fn': 0, 'dropout_prob': 0.2476540471215125, 'optimizer': 0}
3589/3589 [==============================] - 0s 49us/step
=================================
Test Accuracy:  0.45528002229863535
```

In an earlier test I also tried 3 different activation functions namely ReLu, Sigmoid and tanh, but since the other 2 gave me extremely poor results I defaulted to just using ReLu.

Convolution Neural Networks:

Like the FNN case, we create a CNN model using the keras library APIs. Similar to the FNN case, we try to optimise the model using the validation set and different combinations of hyperparameters to optimise the model.

Firstly I used a simple for loop which used the following params and trained 10 different models, the best hyperparameter pair from this was used on the test set.

```
dropout_range = [0.1,0.2,0.3,0.4,0.5]
kernels = [2,3]
```

```
Best Feature Pair is: 3 and 0.3
Best performance from training: 0.45082195598489894
Kernel Size: 3
Dropout: 0.3
```

```
3589/3589 [==============================] - 2s 522us/step
Accuracy on Test samples: 0.2449150181191982
```

Unfortunately, this was not yielding very good results because I was only using a small set of values. So once again I used HyperOpt to find a better set of hyperparameters.

```
---------------------------------------------------
100%|██████████| 25/25 [12:46<00:00, 30.65s/it, best loss: -0.5937587071939842]
==================================
Best Hyperparameters {'conv_kernel_size': 1, 'dropout_prob': 0.2890305052408365, 'optimizer': 0}
3589/3589 [==============================] - 0s 102us/step
==================================
Test Accuracy:  0.5851212036862085
```

Fine Tuning:

I was a little unclear about this part so I have done 2 things.
The first thing is to train a model on the MNIST dataset and modify the FER dataset suitably to work with the trained model. Doing this got an accuracy of 40%

```
Model: "sequential_29"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_9 (Conv2D)            (None, 26, 26, 32)        320
_________________________________________________________________
conv2d_10 (Conv2D)           (None, 24, 24, 32)        9248
_________________________________________________________________
max_pooling2d_5 (MaxPooling2 (None, 12, 12, 32)        0
_________________________________________________________________
dropout_31 (Dropout)         (None, 12, 12, 32)        0
_________________________________________________________________
conv2d_11 (Conv2D)           (None, 10, 10, 64)        18496
_________________________________________________________________
conv2d_12 (Conv2D)           (None, 8, 8, 64)          36928
_________________________________________________________________
max_pooling2d_6 (MaxPooling2 (None, 4, 4, 64)          0
_________________________________________________________________
dropout_32 (Dropout)         (None, 4, 4, 64)          0
_________________________________________________________________
flatten_3 (Flatten)          (None, 1024)              0
_________________________________________________________________
dense_31 (Dense)             (None, 512)               524800
_________________________________________________________________
dense_32 (Dense)             (None, 10)                5130
=================================================================
Total params: 594,922
Trainable params: 594,922
Non-trainable params: 0
```

Then adding another layer for the outputs of FER,

```
Model: "sequential_29"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_9 (Conv2D)            (None, 26, 26, 32)        320
_________________________________________________________________
conv2d_10 (Conv2D)           (None, 24, 24, 32)        9248
_________________________________________________________________
max_pooling2d_5 (MaxPooling2 (None, 12, 12, 32)        0
_________________________________________________________________
dropout_31 (Dropout)         (None, 12, 12, 32)        0
_________________________________________________________________
conv2d_11 (Conv2D)           (None, 10, 10, 64)        18496
_________________________________________________________________
conv2d_12 (Conv2D)           (None, 8, 8, 64)          36928
_________________________________________________________________
max_pooling2d_6 (MaxPooling2 (None, 4, 4, 64)          0
_________________________________________________________________
dropout_32 (Dropout)         (None, 4, 4, 64)          0
_________________________________________________________________
flatten_3 (Flatten)          (None, 1024)              0
_________________________________________________________________
dense_31 (Dense)             (None, 512)               524800
_________________________________________________________________
dense_32 (Dense)             (None, 10)                5130
_________________________________________________________________
dense_35 (Dense)             (None, 7)                 77
=================================================================
Total params: 659,914
Trainable params: 594,922
Non-trainable params: 64,992
```

The final model accuracy:

```
3589/3589 [==============================] - 1s 232us/step
Accuracy on Test samples: 0.4093062134299248
```

The second thing was to create a combined model of FER and MNIST.

```
Model: "model_1"
__________________________________________________________________________________________________
Layer (type)                    Output Shape         Param #     Connected to
==================================================================================================
input_1 (InputLayer)            (None, 28, 28, 1)    0
__________________________________________________________________________________________________
input_2 (InputLayer)            (None, 48, 48, 1)    0
__________________________________________________________________________________________________
sequential_2 (Sequential)       multiple             98272       input_1[0][0]
                                                                 input_2[0][0]
__________________________________________________________________________________________________
MNIST (Dense)                   (None, 10)           81930       sequential_2[1][0]
__________________________________________________________________________________________________
FER (Dense)                     (None, 7)            290311      sequential_2[2][0]
==================================================================================================
Total params: 470,513
Trainable params: 470,513
Non-trainable params: 0
```

This yielded the following results,

```
===
MNIST Accuracy: 0.9875731395127282
FER Accuracy: 0.8625562360739103
```

Data Augmentation:

In this section we look at different types of data augmentation using the ImageDataGenerator from keras. I tried Standardisation, ZCA Whitening and Random Rotation, the results are shown below in the same order.

```
==================================
Best Hyperparameters {'conv_kernel_size': 2, 'dropout_prob': 0.21040384851779753, 'optimizer': 0}
3589/3589 [==============================] - 0s 92us/step
==================================
Test Accuracy:  0.6032320980816108
```

```
==================================
Best Hyperparameters {'conv_kernel_size': 2, 'dropout_prob': 0.14865966844802445, 'optimizer': 0}
3589/3589 [==============================] - 0s 112us/step
==================================
Test Accuracy:  0.5918083031568131
```

```
==================================
Best Hyperparameters {'conv_kernel_size': 2, 'dropout_prob': 0.19430122651964926, 'optimizer': 0}
3589/3589 [==============================] - 0s 123us/step
==================================
Test Accuracy:  0.5770409584925612
```

Feature Design:

In this section I tried implementing HOG on the images because it seemed like it would give good results for the task we had intended. Unfortunately, I guess either there is an error in my implementation or HOG is not a method that is suitable for this sort of task. But I attribute it to the former rather than the latter.

```
----------------------------------------------------
Total Training Time is (s):
26.25912308692932
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.10813003008178762, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
----------------------------------------------------
Total Training Time is (s):
21.570691347122192
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.27555616085888457, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
----------------------------------------------------
100%|██████████| 25/25 [10:50<00:00, 26.00s/it, best loss: -0.24937308442878273]
==================================
Best Hyperparameters {'conv_kernel_size': 2, 'dropout_prob': 0.15049653462509077, 'optimizer': 1}
3589/3589 [==============================] - 0s 87us/step
==================================
Test Accuracy:  0.2449150181191982
```

APPENDIX A: COLAB Workbook

DATA EXPLORATION

```
from google.colab import drive
drive.mount('/content/drive')
```

```
Drive already mounted at /content/drive; to attempt to forcibly remount, call drive.m
```

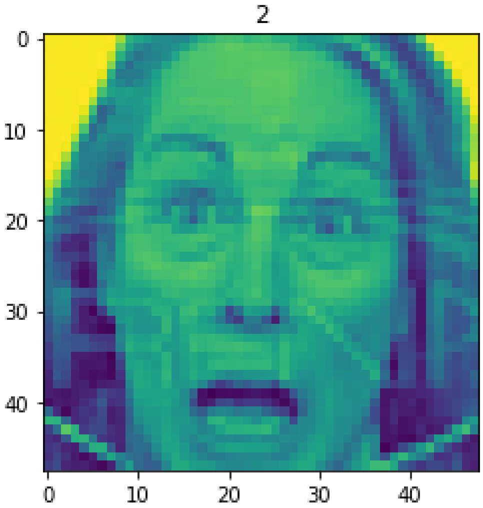
```
#IMPORTING THE DATA FROM THE DATASETS.
import pandas as pd
import numpy as np
import csv
import matplotlib.pyplot as plt
from skimage import data, io, filters

path = "/content/drive/My Drive/Homework3_Data/Train_Data.csv"

path3 = "/content/drive/My Drive/Homework3_Data/Validation_Data.csv"
train_data_df = pd.read_csv(path)

validation_data_df = pd.read_csv(path3)
```

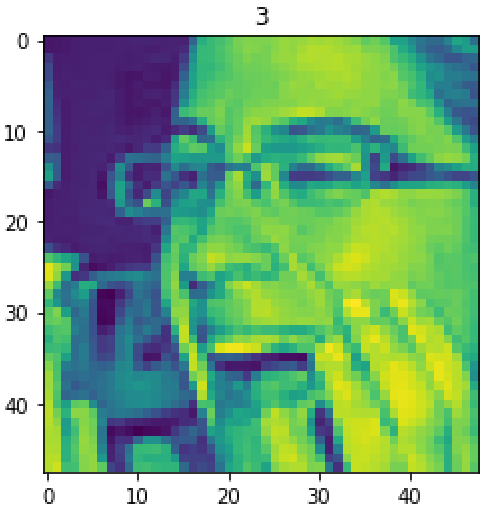
```
#Creating data arrays
train_labels = train_data_df['emotion']
valid_labels = validation_data_df['emotion']

train_pixels = train_data_df.drop('emotion',axis=1)
train_pixels = train_pixels.to_numpy()

valid_pixels = validation_data_df.drop('emotion',axis=1)
valid_pixels = valid_pixels.to_numpy()

def image_display(i):
  image = train_pixels[i][0]
  shape = (48,48)
  image = [int(k) for k in image.split(' ')]
  image = np.array(image)
  image = image.reshape(shape)
  plt.title(train_labels[i])
  plt.imshow(image)
  plt.show()
```

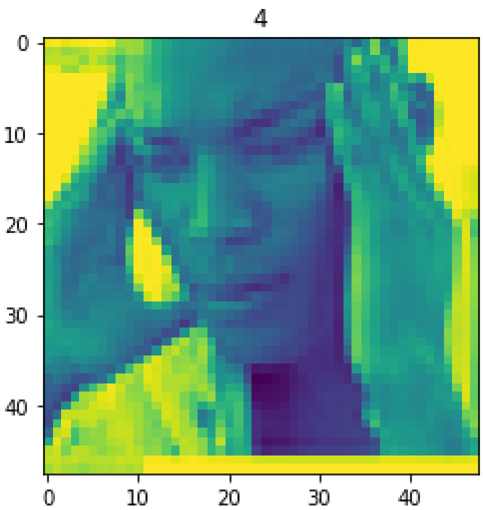
```
#-----------------------------TESTTING STUFF
path2 = "/content/drive/My Drive/Homework3_Data/Test_Data.csv"
test_data_df = pd.read_csv(path2)
test_labels = test_data_df['emotion']

test_pixels = test_data_df.drop('emotion',axis=1)
test_pixels = test_pixels.to_numpy()
test_image_array = []
for i in range (len(test_pixels)):
```

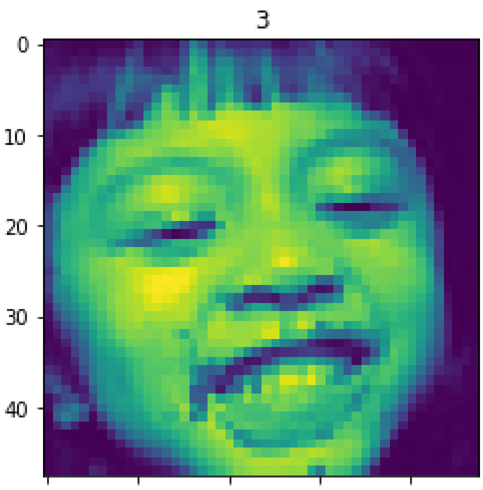
```
  temp = test_pixels[i][0]
  temp = [int(k) for k in temp.split(' ')]
  temp = np.array(temp)
  test_image_array.append(temp)

test_image_array = np.array(test_image_array)

```

```
import random
my_randoms=[]
for i in range (10):
    my_randoms.append(random.randrange(1,len(train_pixels),1))
for i in my_randoms:
  image_display(i)
```

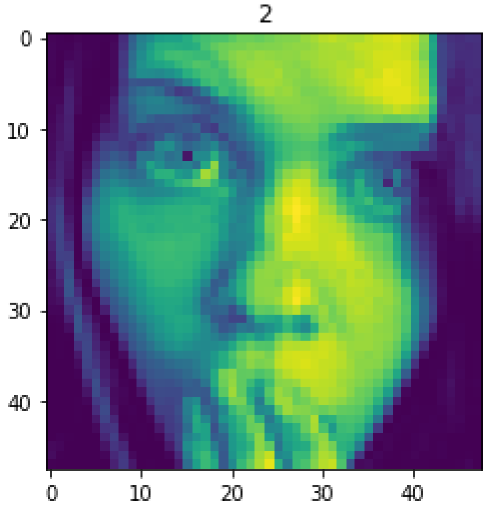

2
0
10
20
30
40
0
10
20
30
40

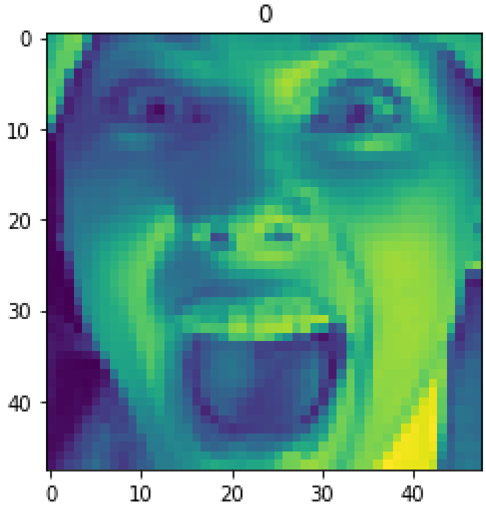

3
0
10
20
30
40
0
10
20
30
40

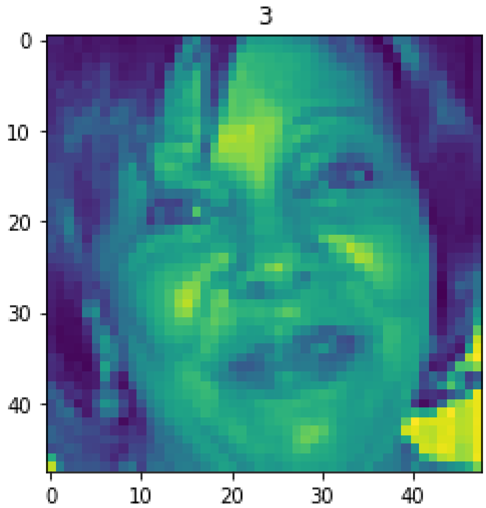

4
0
10
20
30
40
0
10
20
30
40

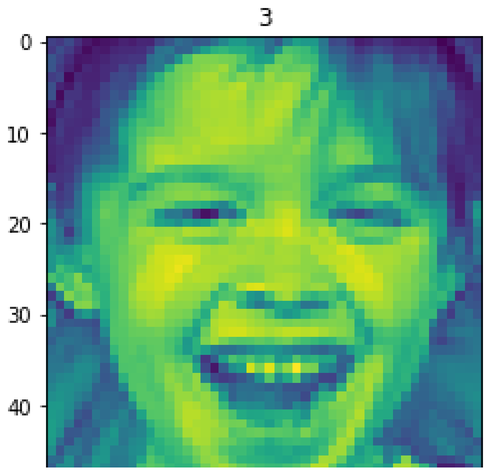

3
0
10
20
30
40

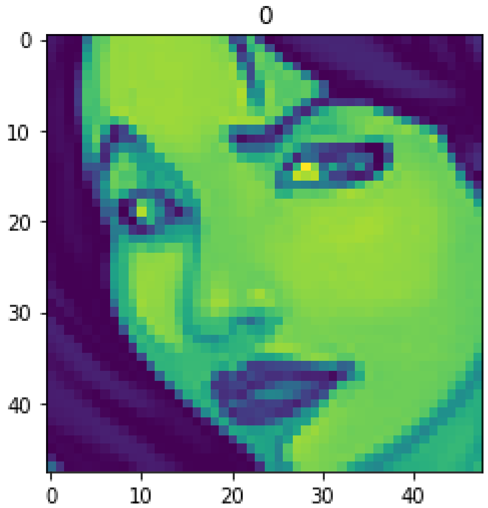
0 10 20 30 40

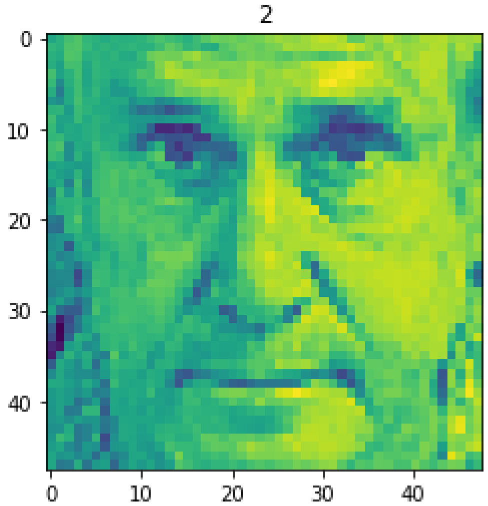

2
0
10
20
30
40
0
10
20
30
40


0
0
10
20
30
40
0
10
20
30
40


3
0
10
20
30
40
0
10
20
30
40


3
0
10
20
30
40






```
count0 = 0
count1 = 0
count2 = 0
count3 = 0
count4 = 0
count5 = 0
count6 = 0
for i in range(len(train_labels)):
  if (train_labels[i]==0):
    count0 += 1
  elif(train_labels[i]==1):
    count1 += 1
  elif(train_labels[i]==2):
    count2 += 1
  elif(train_labels[i]==3):
    count3 += 1
  elif(train_labels[i]==4):
    count4 += 1
  elif(train_labels[i]==5):
    count5 += 1
  elif(train_labels[i]==6):
    count6 += 1
  else:
    print("Oops.")
```

```
    print("Oops!")
total = count0+count1+count2+count3+count4+\
        count5+count6
print("\nAngry:   ",count0,"\nDisgust:  ", count1,"\nFear:    ",count2,\
      "\nHappy:   ",count3,"\nSad:     ",count4,"\nSurprise:" \
      , count5,"\nNeutral: " ,count6,"\n_______\nTotal:  ",total)
```

```
 Angry:    3995
 Disgust:   436
 Fear:     4097
 Happy:    7215
 Sad:      4830
 Surprise: 3171
 Neutral:  4965
 _______
 Total:   28709
```

FNN

```
train_image_array = []
for i in range (len(train_pixels)):
  temp = train_pixels[i][0]
  temp = [int(k) for k in temp.split(' ')]
  temp = np.array(temp)
  train_image_array.append(temp)
```

```
valid_image_array = []
for i in range (len(valid_pixels)):
  temp = valid_pixels[i][0]
  temp = [int(k) for k in temp.split(' ')]
  temp = np.array(temp)
  valid_image_array.append(temp)
```

```
train_image_array = np.array(train_image_array)
valid_image_array = np.array(valid_image_array)
```

```
from skimage import data, io, filters
#noramlise all the images
train_image_array = (train_image_array / 255) - 0.5
valid_image_array = (valid_image_array / 255) -0.5
test_image_array = (test_image_array / 255) -0.5

# train_image_array = filters.sobel(train_image_array)
# valid_image_array = filters.sobel(valid_image_array)
# test_image_array = filters.sobel(test_image_array)
```

```
import warnings
import keras
warnings.filterwarnings("ignore")
from keras.models import Sequential
from keras.layers import Dense, Dropout
```

```
from keras.utils import to_categorical
from keras import regularizers


# # Flatten the images into vectors (1D) for feed forward network
# flatten_train_images = train_image_array.reshape((-1, 48*48))
# flatten_test_images = test_image_array.reshape((-1, 48*48))
# flatten_valid_images = valid_image_array.reshape((-1, 48*48))
```

```
Using TensorFlow backend.
```

The default version of TensorFlow in Colab will soon switch to TensorFlow 2.x.
We recommend you upgrade now or ensure your notebook will continue to use TensorFlow 1.x via the %te

```
import time
class TimeHistory(keras.callbacks.Callback):
    def on_train_begin(self, logs={}):
        self.times = []

    def on_epoch_begin(self, batch, logs={}):
        self.epoch_time_start = time.time()

    def on_epoch_end(self, batch, logs={}):
        self.times.append(time.time() - self.epoch_time_start)
```

```
# Evaluate your model's performance on the test data
def model_test(model):
  performance = model.evaluate(valid_image_array, to_categorical(valid_labels))
  print("\nAccuracy on Test samples: {0}".format(performance[1]))
```

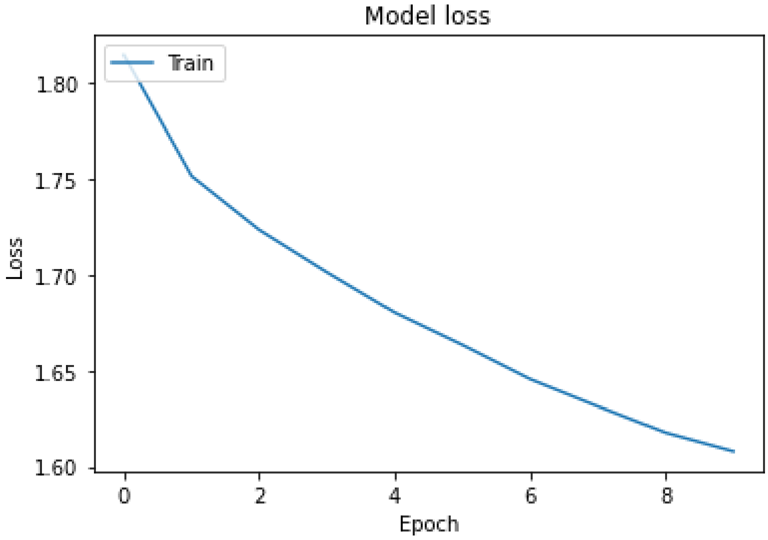
```
# Compiling the model
def model_compile(model):
  model.compile(optimizer='adam', loss='categorical_crossentropy',metrics=['accuracy'],
# Train model
  time_callback = TimeHistory()
  hist = model.fit(train_image_array, to_categorical(train_labels), epochs=10, batch_si

  plt.plot(hist.history['loss'])
  plt.title('Model loss')
  plt.ylabel('Loss')
  plt.xlabel('Epoch')
  plt.legend(['Train'], loc='upper left')
  plt.show()
  print("\nTotal Training Time is: ", sum(time_callback.times),'s.\n')
```

```
from hyperopt import hp, fmin, tpe, STATUS_OK, Trials

#MODEL 1
#Define a Feed-Forward Model with 2 hidden layers with dimensions 392 and 196 Neurons
def optimize_fnn(hyperparameter):
  model = Sequential([
    Dense(2304, activation=hyperparameter['activation_fn'], input_shape=(48*48,), name=
    Dense(2304//2, activation=hyperparameter['activation_fn'], name="second_hidden_laye
    Dense(7, activation='softmax'),
```

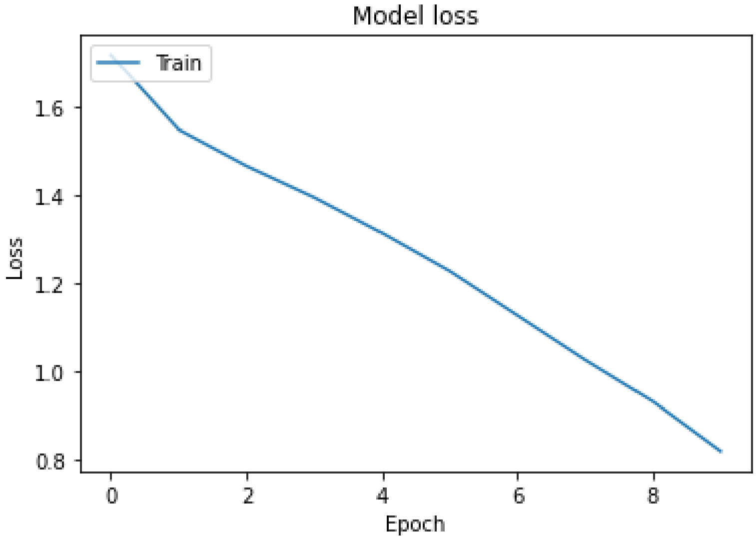
```
    Dense(7, activation='softmax'),
  ])
  #  Validate your Model Architecture
  #print(model1.summary())
  model.compile(optimizer=hyperparameter['optimizer'], loss='categorical_crossentropy',
  time_callback = TimeHistory()
  hist = model.fit(train_image_array, to_categorical(train_labels), epochs=10, batch_si
  plt.plot(hist.history['loss'])
  plt.title('Model loss')
  plt.ylabel('Loss')
  plt.xlabel('Epoch')
  plt.legend(['Train'], loc='upper left')
  plt.show()
  print("Total Training Time is (s): ", sum(time_callback.times))

  performance = model.evaluate(valid_image_array, to_categorical(valid_labels), verbose

  print("Hyperparameters: ", hyperparameter, "Accuracy: ", performance[1])
  print("----------------------------------------------------")
  # We want to minimize loss i.e. negative of accuracy
  return({"status": STATUS_OK, "loss": -1*performance[1], "model":model})

# Define search space for hyper-parameters
space = {
    # The activation_fn choices:
    'activation_fn':hp.choice('activation_fn',['relu']),
    # Uniform distribution in finding appropriate dropout values
    'dropout_prob': hp.uniform('dropout_prob', 0.1, 0.5),
    # Choice of optimizer
    'optimizer': hp.choice('optimizer', ['Adam', 'sgd']),
}

trials = Trials()

best = fmin(
        optimize_fnn,
        space,
        algo=tpe.suggest,
        trials=trials,
        max_evals=25,
    )

print("========================================================================")
print("Best Hyperparameters", best)

# You can retrain the final model with optimal hyperparameters on train+validation data

# Or you can use the model returned directly
# Find trial which has minimum loss value and use that model to perform evaluation on t
test_model = trials.results[np.argmin([r['loss'] for r in trials.results])]['model']

performance = test_model.evaluate(test_image_array, to_categorical(test_labels))

print("==================================")
print("Test Accuracy: ", performance[1])

```

65

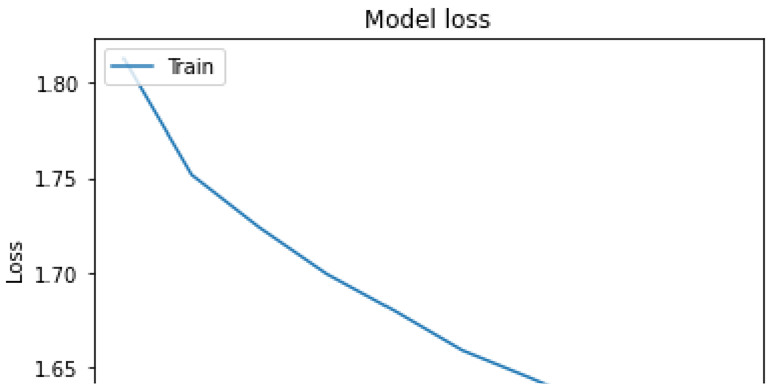
```
  0%|          | 0/25 [00:00<?, ?it/s, best loss: ?]
```

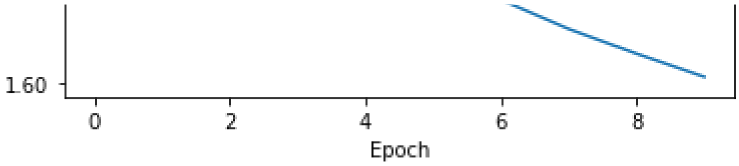



```
Total Training Time is (s):
7.4364213943481445
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.25336800158266903, 'optimizer': 'sgd'}
Accuracy:
0.39091668988991396
----------------------------------------------------
  4%|▍         | 1/25 [00:07<03:11,  8.00s/it, best loss: -0.39091668988991396]
```

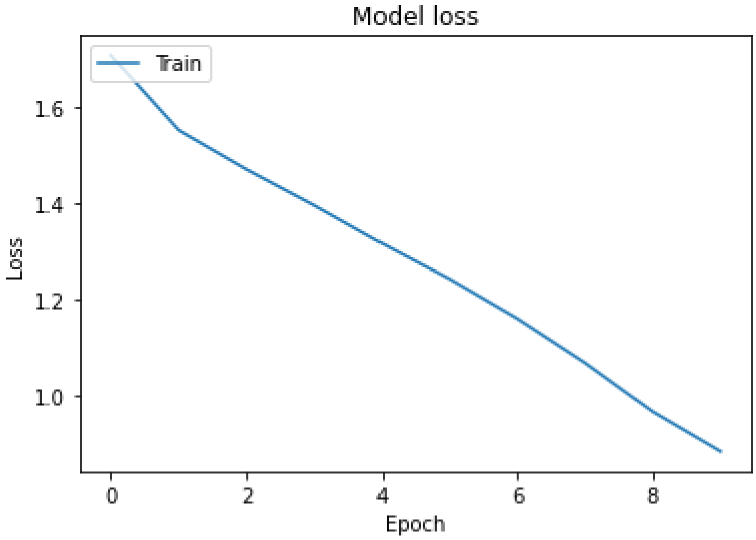



```
Total Training Time is (s):
9.509779930114746
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.10552055620174437, 'optimizer': 'Adam'}
Accuracy:
0.4488715519726393
----------------------------------------------------
  8%|▊         | 2/25 [00:18<03:19,  8.66s/it, best loss: -0.4488715519726393]
```

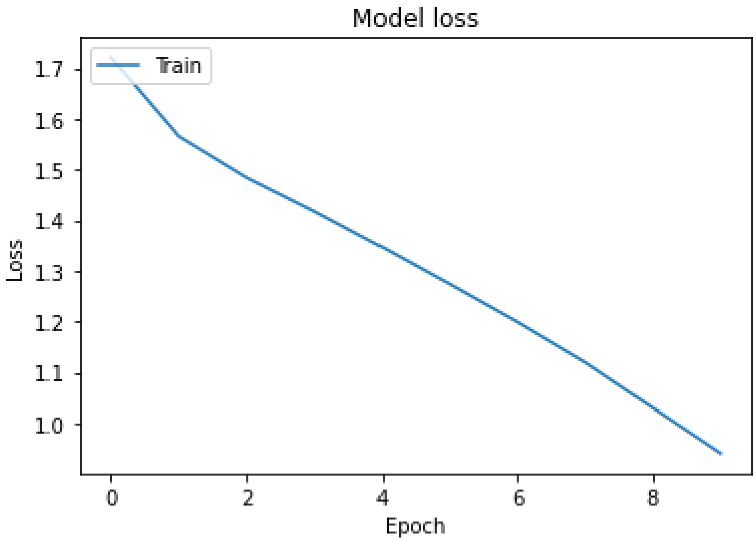




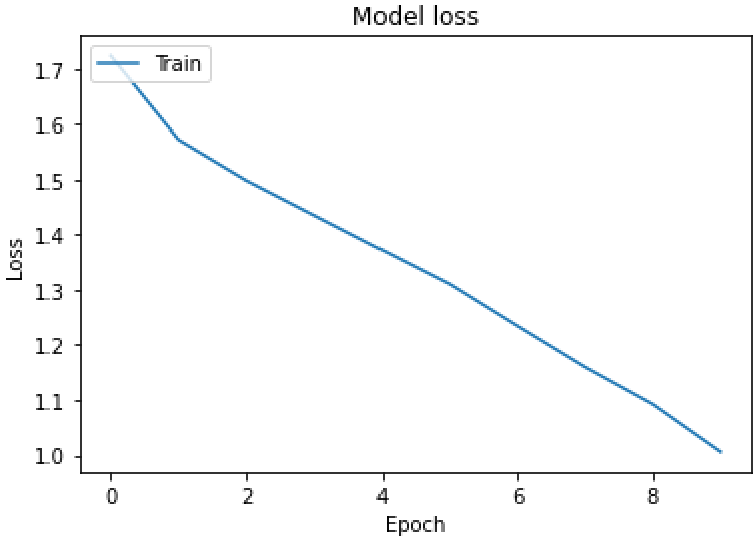

```
Total Training Time is (s):
7.328493356704712
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.1759849523388486, 'optimizer': 'sgd'}
Accuracy:
0.38311507384502713
----------------------------------------------------
 12%|█          | 3/25 [00:26<03:05,  8.44s/it, best loss: -0.4488715519726393]
```



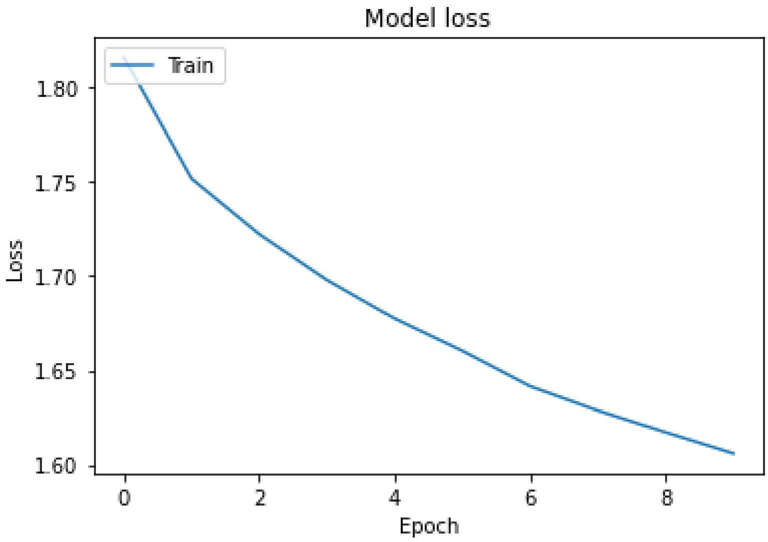

```
Total Training Time is (s):
9.538674116134644
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.18842808735315886, 'optimizer': 'Adam'}
Accuracy:
0.4555586514681553
----------------------------------------------------
 16%|█          | 4/25 [00:36<03:08,  8.98s/it, best loss: -0.4555586514681553]
```



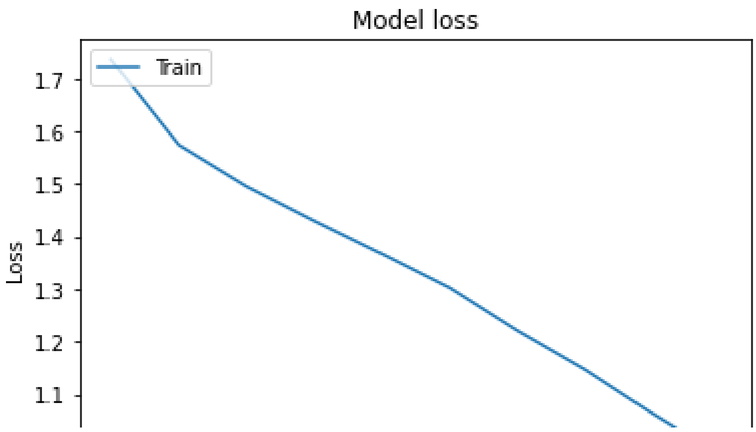

```
Total Training Time is (s):
9.489769220352173
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.2476540471215125, 'optimizer': 'Adam'}
Accuracy:
0.4636388966368912
----------------------------------------------------
 20%|██         | 5/25 [00:46<03:07,  9.35s/it, best loss: -0.4636388966368912]
```

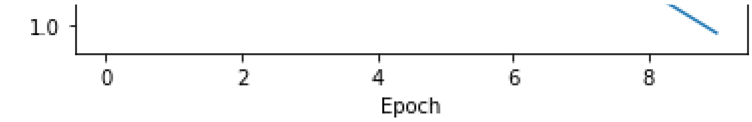



```
Total Training Time is (s):
9.495479583740234
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.3644742571285925, 'optimizer': 'Adam'}
Accuracy:
0.44859292282803076
-----------------------------------------------------
 24%|██          | 6/25 [00:56<03:02,  9.62s/it, best loss: -0.4636388966368912]
```

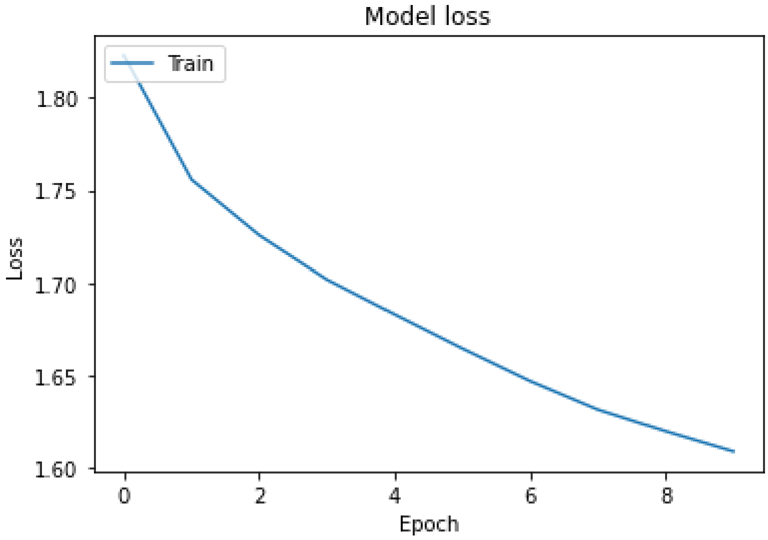



```
Total Training Time is (s):
7.4017863273620605
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.2555559787727395, 'optimizer': 'sgd'}
Accuracy:
0.3842295904234612
-----------------------------------------------------
 28%|███         | 7/25 [01:04<02:44,  9.15s/it, best loss: -0.4636388966368912]
```

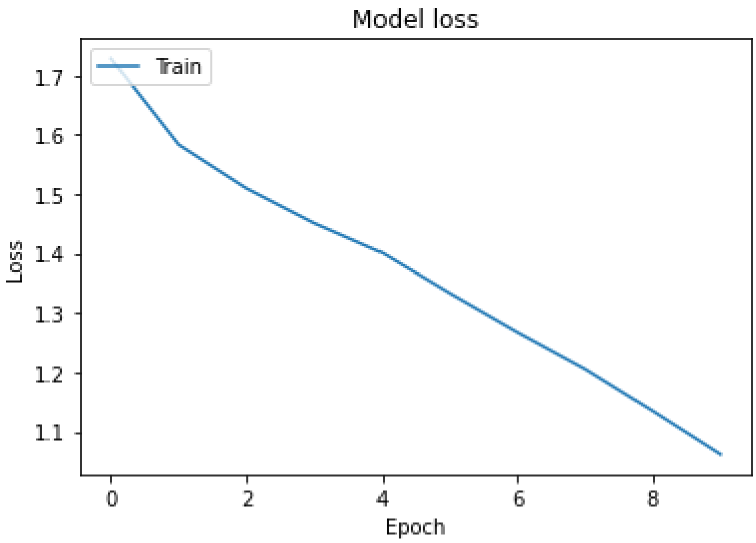





```
Total Training Time is (s):
9.604174613952637
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.32319345246869036, 'optimizer': 'Adam'}
Accuracy:
0.45277236002207
----------------------------------------------------
 32%|███         | 8/25 [01:15<02:42,  9.57s/it, best loss: -0.4636388966368912]
```

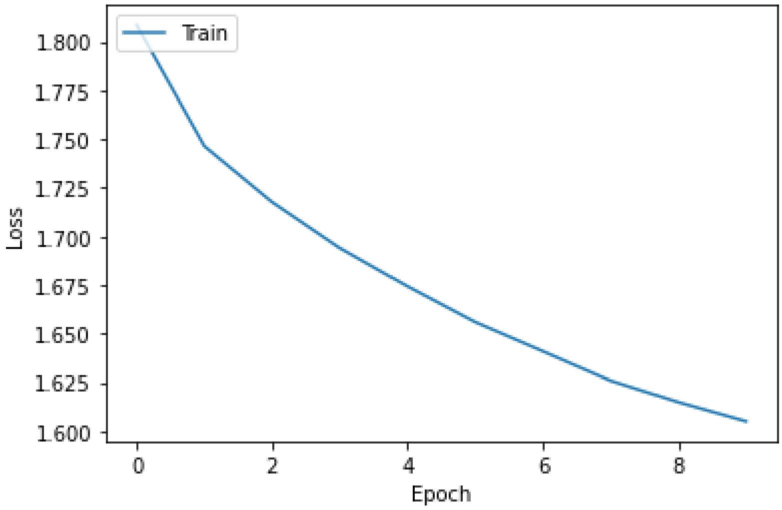



```
Total Training Time is (s):
7.4649622440338135
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.3406336734941001, 'optimizer': 'sgd'}
Accuracy:
0.38255781556411383
----------------------------------------------------
 36%|████        | 9/25 [01:23<02:26,  9.15s/it, best loss: -0.4636388966368912]
```

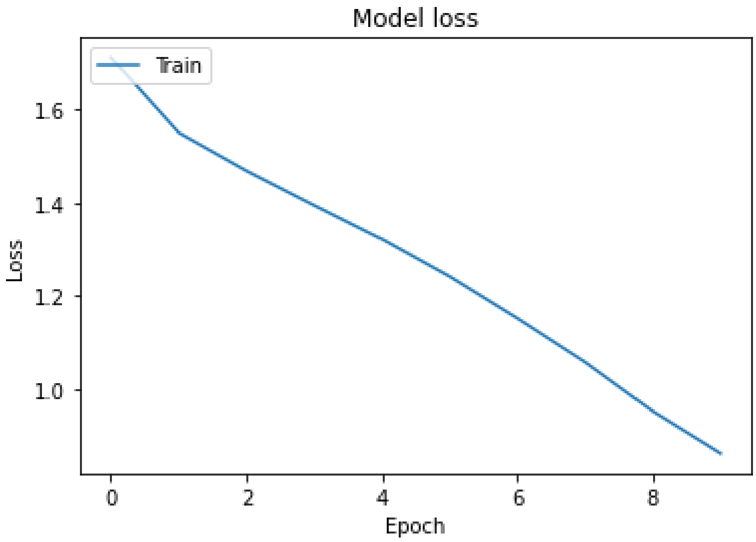



```
Total Training Time is (s):
9.565871000289917
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.4370333627480284, 'optimizer': 'Adam'}
Accuracy:
0.44998606855107337
----------------------------------------------------
 40%|████        | 10/25 [01:34<02:22,  9.52s/it, best loss: -0.4636388966368912]
```

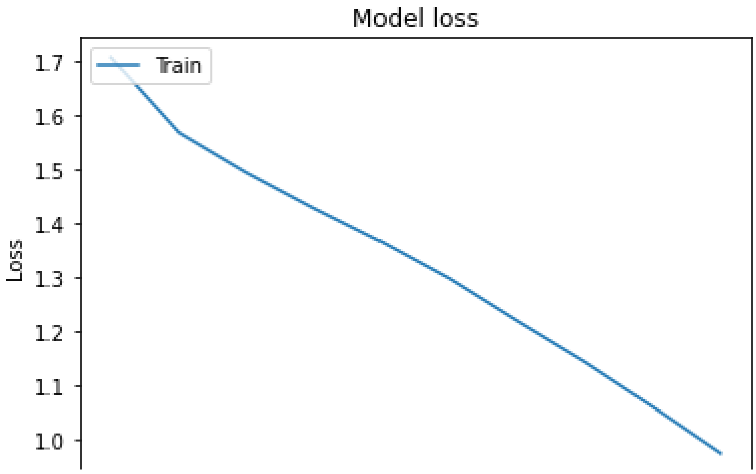
Model loss



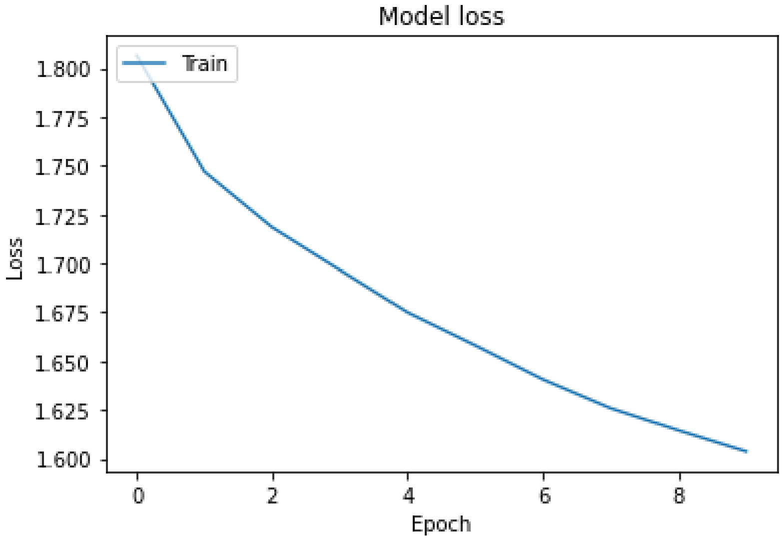

```
Total Training Time is (s):
7.352118968963623
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.2464429141873418, 'optimizer': 'sgd'}
Accuracy:
0.3836723321342442
-----------------------------------------------------
 44%|████      | 11/25 [01:42<02:07,  9.10s/it, best loss: -0.4636388966368912]
```



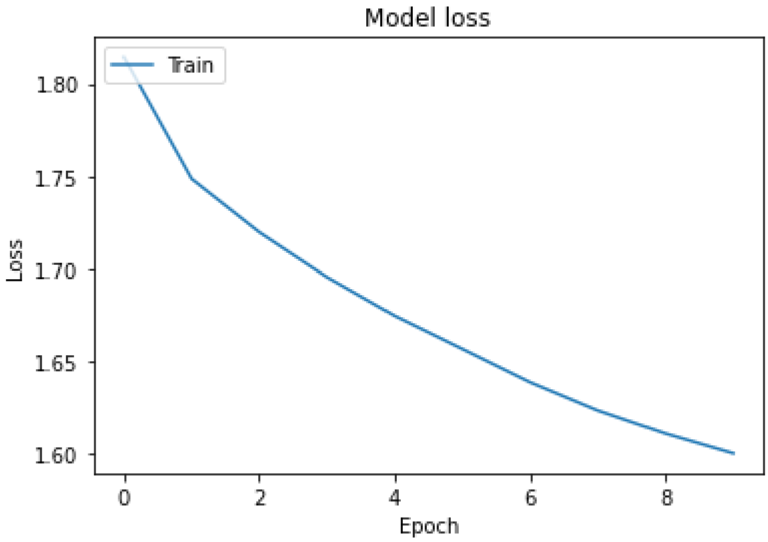

```
Total Training Time is (s):
9.775615215301514
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.1675727368174647, 'optimizer': 'Adam'}
Accuracy:
0.4533296182863757
-----------------------------------------------------
 48%|████▊     | 12/25 [01:52<02:04,  9.56s/it, best loss: -0.4636388966368912]
```



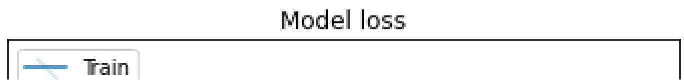

```
Total Training Time is (s):
9.897839069366455
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.3479228659873571, 'optimizer': 'Adam'}
Accuracy:
0.4488715519726393
-----------------------------------------------------
 52%|█████     | 13/25 [02:03<01:59,  9.93s/it, best loss: -0.4636388966368912]
```

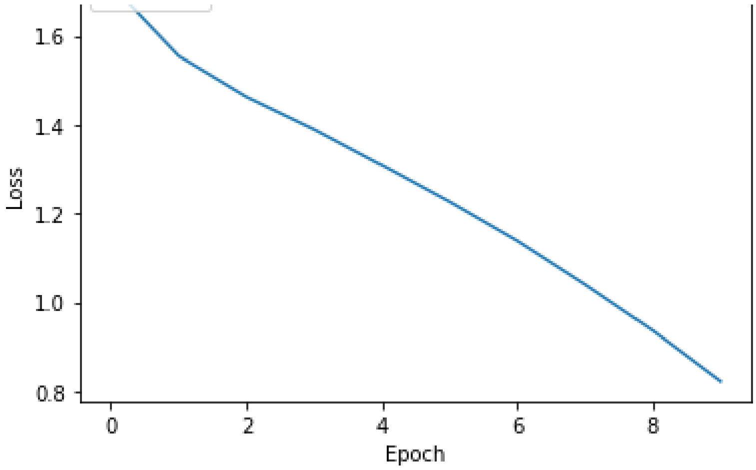



```
Total Training Time is (s):
7.853139162063599
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.23118676879866445, 'optimizer': 'sgd'}
Accuracy:
0.3898021733156317
-----------------------------------------------------
 56%|█████▌    | 14/25 [02:12<01:45,  9.55s/it, best loss: -0.4636388966368912]
```



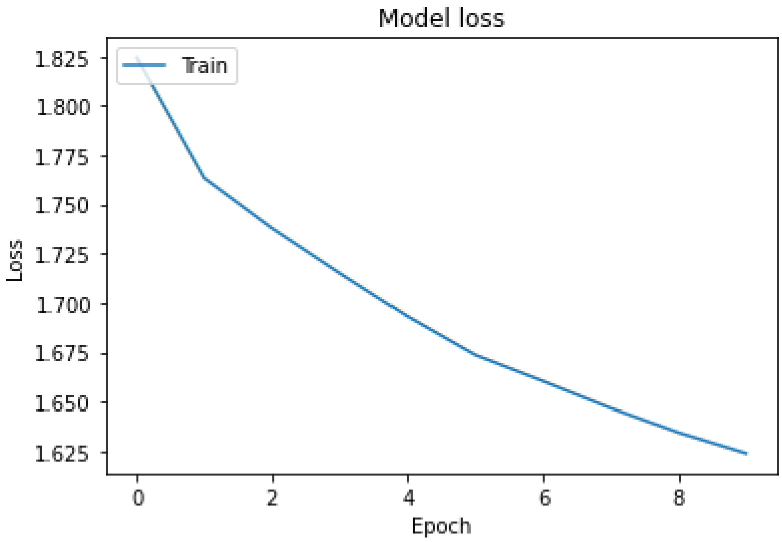

```
Total Training Time is (s):
7.92191481590271
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.11349796190538407, 'optimizer': 'sgd'}
Accuracy:
0.3870158818695465
-----------------------------------------------------
 60%|██████    | 15/25 [02:20<01:33,  9.31s/it, best loss: -0.4636388966368912]
```





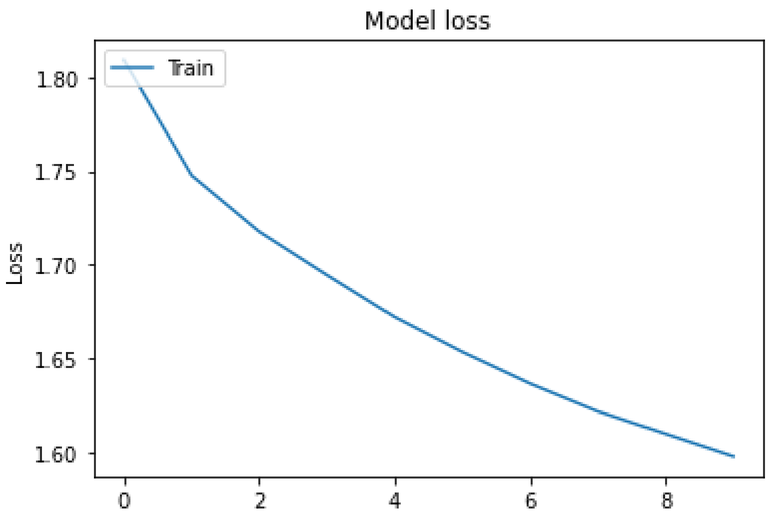
Total Training Time is (s):
10.156506061553955
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.10106341569977983, 'optimizer': 'Adam'}
Accuracy:
0.44051267765929486

 64%|████████ | 16/25 [02:32<01:28, 9.83s/it, best loss: -0.4636388966368912]



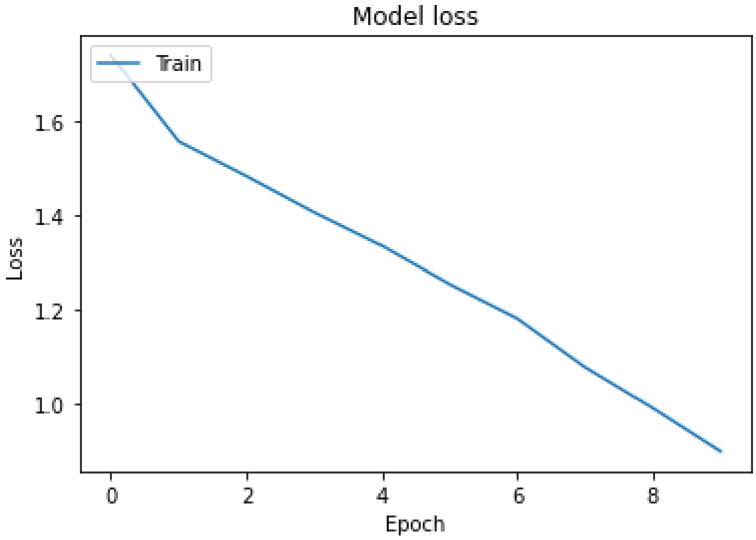
Total Training Time is (s):
8.006651639938354
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.49276434949032477, 'optimizer': 'sgd'}
Accuracy:
0.38478684870852636

 68%|████████▊ | 17/25 [02:40<01:16, 9.55s/it, best loss: -0.4636388966368912]

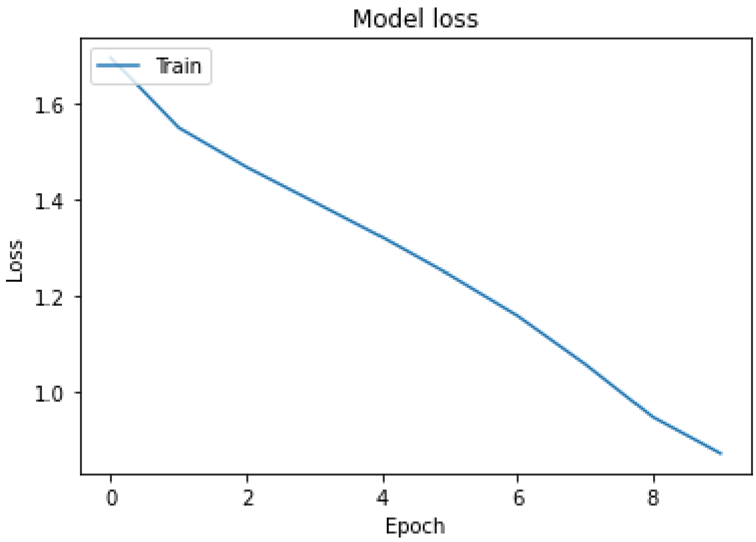


Epoch

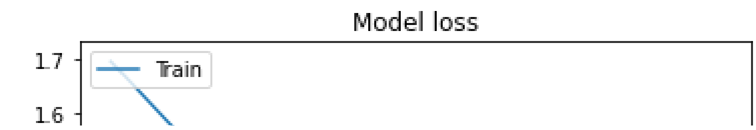
```
Total Training Time is (s):
8.145221471786499
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.11279906259430761, 'optimizer': 'sgd'}
Accuracy:
0.3825578155516582
----------------------------------------------------
 72%|        | 18/25 [02:50<01:06,  9.44s/it, best loss: -0.4636388966368912]
```

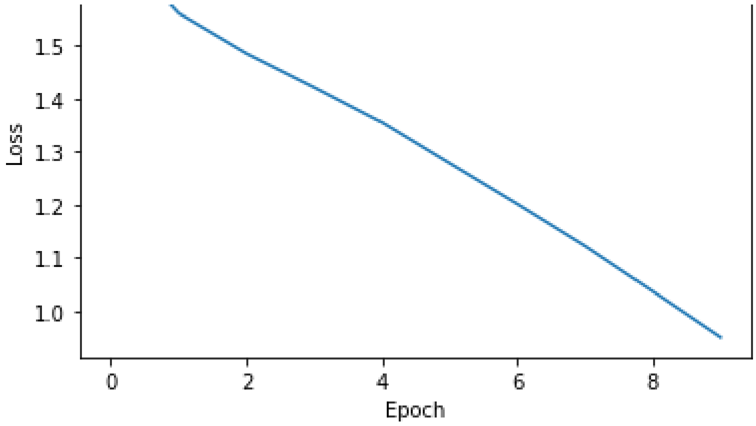



```
Total Training Time is (s):
10.069785594940186
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.21733738187782758, 'optimizer': 'Adam'}
Accuracy:
0.45834494288517724
----------------------------------------------------
 76%|        | 19/25 [03:01<00:59,  9.93s/it, best loss: -0.4636388966368912]
```



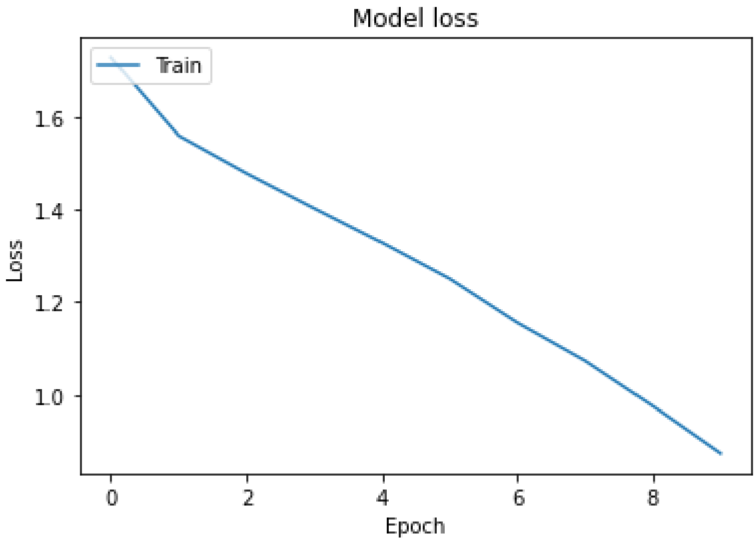

```
Total Training Time is (s):
10.192638874053955
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.14335957639670258, 'optimizer': 'Adam'}
Accuracy:
0.4589022011785462
----------------------------------------------------
 80%|        | 20/25 [03:12<00:51, 10.32s/it, best loss: -0.4636388966368912]
```





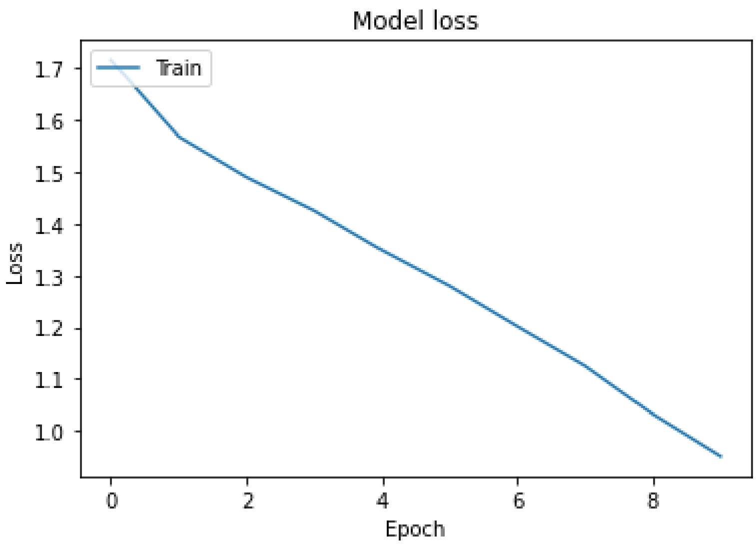
Total Training Time is (s):
10.345960855484009
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.2936624860958402, 'optimizer': 'Adam'}
Accuracy:
0.45110058512950746

 84%| | 21/25 [03:23<00:42, 10.64s/it, best loss: -0.4636388966368912]

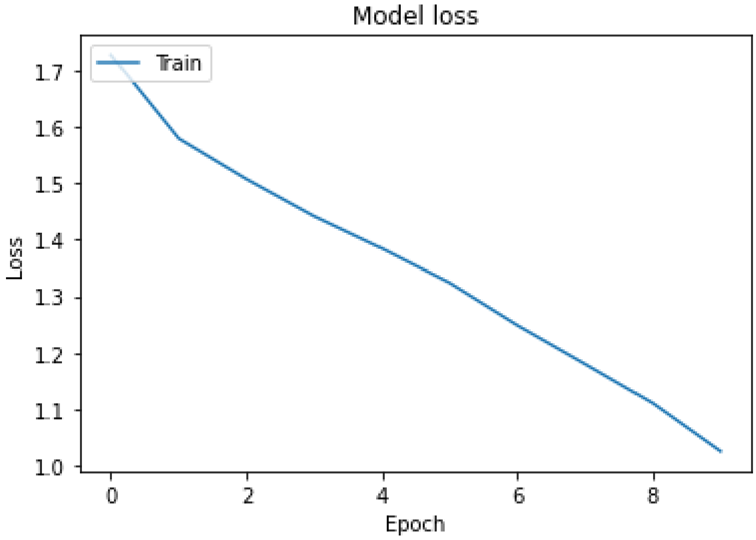


Total Training Time is (s):
10.243130207061768
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.15123480999583044, 'optimizer': 'Adam'}
Accuracy:
0.4494288102618563

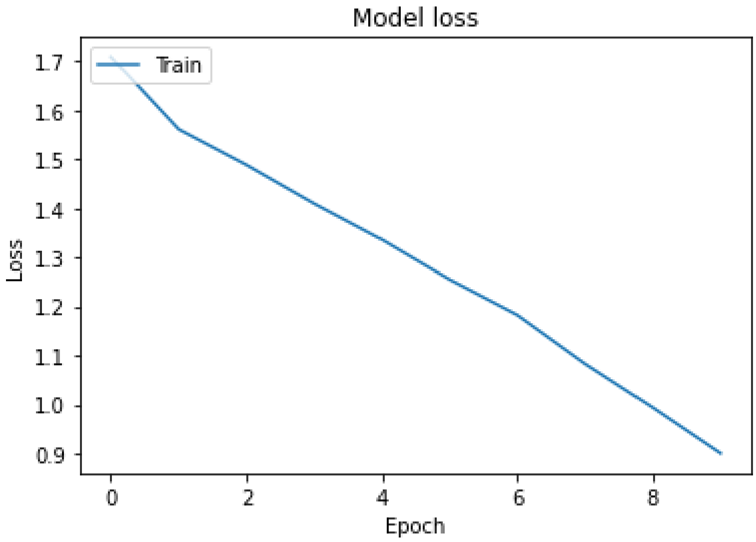
 88%| | 22/25 [03:35<00:32, 10.84s/it, best loss: -0.4636388966368912]



```
Total Training Time is (s):
10.352617740631104
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.2890076526664475, 'optimizer': 'Adam'}
Accuracy:
0.44524937309272844
-----------------------------------------------------
 92%|█████████▏ | 23/25 [03:46<00:22, 11.03s/it, best loss: -0.4636388966368912]
```




```
Total Training Time is (s):
10.280369758605957
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.40388349489252084, 'optimizer': 'Adam'}
Accuracy:
0.45082195600981034
-----------------------------------------------------
 96%|█████████▌| 24/25 [03:57<00:11, 11.13s/it, best loss: -0.4636388966368912]
```




```
Total Training Time is (s):
10.576332807540894
Hyperparameters:
{'activation_fn': 'relu', 'dropout_prob': 0.2051775684138893, 'optimizer': 'Adam'}
Accuracy:
0.45277236002207
-----------------------------------------------------
100%|██████████| 25/25 [04:09<00:00,  9.98s/it, best loss: -0.4636388966368912]
======================================================================
Best Hyperparameters {'activation_fn': 0, 'dropout_prob': 0.2476540471215125, 'optimi
3589/3589 [==============================] - 0s 49us/step
=================================
Test Accuracy:  0.45528002229863535
```

CNNs

```
from keras.layers import Conv2D, Flatten, MaxPooling2D

# Flatten the images into vectors (1D) for feed forward network
train_images_3d = train_image_array.reshape((len(train_image_array),48,48,1))
test_images_3d = test_image_array.reshape((len(test_image_array), 48,48,1))
valid_images_3d = valid_image_array.reshape((len(valid_image_array), 48,48,1))

# Define 2 groups of layers: features layer (convolutions) and classification layer
common_features = [Conv2D(64, kernel_size=(3,3), strides=3, activation='relu', input_sh
            Conv2D(64, kernel_size=(3,3), activation='relu'),
            MaxPooling2D(pool_size=(2,2)), Dropout(0.3),
            Conv2D(128, kernel_size=3, activation='relu'),
            Conv2D(128, kernel_size=3, activation='relu'),
            MaxPooling2D(pool_size=(2,2)), Dropout(0.3), Flatten(),]

classifier = [Dense(512, activation='relu'), Dense(7, activation='relu'),]
cnn_model = Sequential(common_features+classifier)
print(cnn_model.summary())
cnn_model.compile(optimizer='adam', loss='categorical_crossentropy',metrics=['accuracy'
```

```
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorfl

Model: "sequential_27"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_1 (Conv2D)            (None, 16, 16, 64)        640
_________________________________________________________________
conv2d_2 (Conv2D)            (None, 14, 14, 64)        36928
_________________________________________________________________
max_pooling2d_1 (MaxPooling2 (None, 7, 7, 64)          0
_________________________________________________________________
dropout_27 (Dropout)         (None, 7, 7, 64)          0
_________________________________________________________________
conv2d_3 (Conv2D)            (None, 5, 5, 128)         73856
_________________________________________________________________
conv2d_4 (Conv2D)            (None, 3, 3, 128)         147584
_________________________________________________________________
max_pooling2d_2 (MaxPooling2 (None, 1, 1, 128)         0
_________________________________________________________________
dropout_28 (Dropout)         (None, 1, 1, 128)         0
_________________________________________________________________
flatten_1 (Flatten)          (None, 128)               0
_________________________________________________________________
dense_27 (Dense)             (None, 512)               66048
_________________________________________________________________
dense_28 (Dense)             (None, 7)                 3591
=================================================================
Total params: 328,647
Trainable params: 328,647
Non-trainable params: 0
_________________________________________________________________
None
```

```
from keras.layers import Conv2D, Flatten, MaxPooling2D
def run_cnn_model(kSize, dropout_rate):
  # Define 2 groups of layers: features layer (convolutions) and classification layer
  common_features = [Conv2D(64, kernel_size=(kSize), strides=3, activation='relu', inpu
              Conv2D(64, kernel_size=(kSize), activation='relu'),
              MaxPooling2D(pool_size=(2,2)), Dropout(dropout_rate),
              Conv2D(128, kernel_size=(kSize), activation='relu'),
              Conv2D(128, kernel_size=(kSize), activation='relu'),
              MaxPooling2D(pool_size=(2,2)), Dropout(dropout_rate), Flatten(),]

  classifier = [Dense(512, activation='relu'), Dense(7, activation='relu'),]
  cnn_model = Sequential(common_features+classifier)
  print("Kernel Size: {0} \nDropout: {1}".format(kSize,dropout_rate))
  print(cnn_model.summary())
  cnn_model.compile(optimizer='adam', loss='categorical_crossentropy',metrics=['accurac
  # Train model
  cnn_model.fit(train_images_3d, to_categorical(train_labels), epochs=10, batch_size=25

  performance = cnn_model.evaluate(valid_images_3d, to_categorical(valid_labels))
  print("Accuracy on Test samples: {0}".format(performance[1]))
  results.append(performance[1])
```

```
  results.append(performance[1])

```

```
dropout_range = [0.1,0.2,0.3,0.4,0.5]
kernels = [2,3]
featureK = []
featureD = []
# Flatten the images into vectors (1D) for feed forward network
train_images_3d = train_image_array.reshape((len(train_image_array),48,48,1))
test_images_3d = test_image_array.reshape((len(test_image_array), 48,48,1))
valid_images_3d = valid_image_array.reshape((len(valid_image_array), 48,48,1))
results = []
for i in dropout_range:
  for j in kernels:
    run_cnn_model(j,i)
    featureK.append(j)
    featureD.append(i)
print(results)
```

```
Kernel Size: 2
Dropout: 0.1
Model: "sequential_29"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_113 (Conv2D)          (None, 16, 16, 64)        320       
_________________________________________________________________
conv2d_114 (Conv2D)          (None, 15, 15, 64)        16448     
_________________________________________________________________
max_pooling2d_57 (MaxPooling (None, 7, 7, 64)          0         
_________________________________________________________________
dropout_57 (Dropout)         (None, 7, 7, 64)          0         
_________________________________________________________________
conv2d_115 (Conv2D)          (None, 6, 6, 128)         32896     
_________________________________________________________________
conv2d_116 (Conv2D)          (None, 5, 5, 128)         65664     
_________________________________________________________________
max_pooling2d_58 (MaxPooling (None, 2, 2, 128)         0         
_________________________________________________________________
dropout_58 (Dropout)         (None, 2, 2, 128)         0         
_________________________________________________________________
flatten_29 (Flatten)         (None, 512)               0         
_________________________________________________________________
dense_57 (Dense)             (None, 512)               262656    
_________________________________________________________________
dense_58 (Dense)             (None, 7)                 3591      
=================================================================
Total params: 381,575
Trainable params: 381,575
Non-trainable params: 0
_________________________________________________________________
None
Epoch 1/10
28709/28709 [==============================] - 4s 130us/step - loss: 3.7096 - acc: 0.
Epoch 2/10
28709/28709 [==============================] - 1s 44us/step - loss: 1.9558 - acc: 0.2
Epoch 3/10
28709/28709 [==============================] - 1s 44us/step - loss: 1.9367 - acc: 0.2
Epoch 4/10
28709/28709 [==============================] - 1s 44us/step - loss: 1.9275 - acc: 0.2
Epoch 5/10
28709/28709 [==============================] - 1s 44us/step - loss: 1.9317 - acc: 0.2
Epoch 6/10
28709/28709 [==============================] - 1s 43us/step - loss: 1.9115 - acc: 0.2
Epoch 7/10
28709/28709 [==============================] - 1s 43us/step - loss: 1.8791 - acc: 0.3
Epoch 8/10
28709/28709 [==============================] - 1s 44us/step - loss: 1.8719 - acc: 0.3
Epoch 9/10
28709/28709 [==============================] - 1s 44us/step - loss: 1.8369 - acc: 0.3
Epoch 10/10
28709/28709 [==============================] - 1s 43us/step - loss: 1.8920 - acc: 0.3
3589/3589 [==============================] - 1s 334us/step
Accuracy on Test samples: 0.24965171357339125
Kernel Size: 3
Dropout: 0.1
Model: "sequential_30"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
```

```
conv2d_117 (Conv2D)          (None, 16, 16, 64)        640
_________________________________________________________________
conv2d_118 (Conv2D)          (None, 14, 14, 64)        36928
_________________________________________________________________
max_pooling2d_59 (MaxPooling (None, 7, 7, 64)          0
_________________________________________________________________
dropout_59 (Dropout)         (None, 7, 7, 64)          0
_________________________________________________________________
conv2d_119 (Conv2D)          (None, 5, 5, 128)         73856
_________________________________________________________________
conv2d_120 (Conv2D)          (None, 3, 3, 128)         147584
_________________________________________________________________
max_pooling2d_60 (MaxPooling (None, 1, 1, 128)         0
_________________________________________________________________
dropout_60 (Dropout)         (None, 1, 1, 128)         0
_________________________________________________________________
flatten_30 (Flatten)         (None, 128)               0
_________________________________________________________________
dense_59 (Dense)             (None, 512)               66048
_________________________________________________________________
dense_60 (Dense)             (None, 7)                 3591
=================================================================
Total params: 328,647
Trainable params: 328,647
Non-trainable params: 0
_________________________________________________________________
None
Epoch 1/10
28709/28709 [==============================] - 4s 135us/step - loss: 4.3348 - acc: 0.
Epoch 2/10
28709/28709 [==============================] - 1s 46us/step - loss: 4.2666 - acc: 0.2
Epoch 3/10
28709/28709 [==============================] - 1s 46us/step - loss: 4.2487 - acc: 0.2
Epoch 4/10
28709/28709 [==============================] - 1s 47us/step - loss: 4.2666 - acc: 0.2
Epoch 5/10
28709/28709 [==============================] - 1s 46us/step - loss: 4.2508 - acc: 0.2
Epoch 6/10
28709/28709 [==============================] - 1s 46us/step - loss: 4.2085 - acc: 0.3
Epoch 7/10
28709/28709 [==============================] - 1s 46us/step - loss: 4.1103 - acc: 0.3
Epoch 8/10
28709/28709 [==============================] - 1s 47us/step - loss: 4.0372 - acc: 0.3
Epoch 9/10
28709/28709 [==============================] - 1s 47us/step - loss: 4.0335 - acc: 0.3
Epoch 10/10
28709/28709 [==============================] - 1s 46us/step - loss: 4.0242 - acc: 0.3
3589/3589 [==============================] - 1s 363us/step
Accuracy on Test samples: 0.3700195040567302
Kernel Size: 2
Dropout: 0.2
Model: "sequential_31"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_121 (Conv2D)          (None, 16, 16, 64)        320
_________________________________________________________________
conv2d_122 (Conv2D)          (None, 15, 15, 64)        16448
_________________________________________________________________
max_pooling2d_61 (MaxPooling (None, 7, 7, 64)          0
_________________________________________________________________
dropout_61 (Dropout)         (None, 7, 7, 64)          0
```

```
dropout_61 (Dropout)         (None, 7, 7, 64)          0
_________________________________________________________________
conv2d_123 (Conv2D)          (None, 6, 6, 128)         32896
_________________________________________________________________
conv2d_124 (Conv2D)          (None, 5, 5, 128)         65664
_________________________________________________________________
max_pooling2d_62 (MaxPooling (None, 2, 2, 128)         0
_________________________________________________________________
dropout_62 (Dropout)         (None, 2, 2, 128)         0
_________________________________________________________________
flatten_31 (Flatten)         (None, 512)               0
_________________________________________________________________
dense_61 (Dense)             (None, 512)               262656
_________________________________________________________________
dense_62 (Dense)             (None, 7)                 3591
=================================================================
Total params: 381,575
Trainable params: 381,575
Non-trainable params: 0
_________________________________________________________________
None
Epoch 1/10
28709/28709 [==============================] - 4s 141us/step - loss: 5.6505 - acc: 0.
Epoch 2/10
28709/28709 [==============================] - 1s 45us/step - loss: 5.5264 - acc: 0.2
Epoch 3/10
28709/28709 [==============================] - 1s 45us/step - loss: 5.5252 - acc: 0.2
Epoch 4/10
28709/28709 [==============================] - 1s 45us/step - loss: 5.5148 - acc: 0.2
Epoch 5/10
28709/28709 [==============================] - 1s 45us/step - loss: 5.5090 - acc: 0.2
Epoch 6/10
28709/28709 [==============================] - 1s 44us/step - loss: 5.5137 - acc: 0.2
Epoch 7/10
28709/28709 [==============================] - 1s 44us/step - loss: 5.5278 - acc: 0.2
Epoch 8/10
28709/28709 [==============================] - 1s 45us/step - loss: 5.5024 - acc: 0.2
Epoch 9/10
28709/28709 [==============================] - 1s 45us/step - loss: 5.4945 - acc: 0.2
Epoch 10/10
28709/28709 [==============================] - 1s 44us/step - loss: 5.5209 - acc: 0.2
3589/3589 [==============================] - 1s 363us/step
Accuracy on Test samples: 0.2471440512719145
Kernel Size: 3
Dropout: 0.2
Model: "sequential_32"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_125 (Conv2D)          (None, 16, 16, 64)        640
_________________________________________________________________
conv2d_126 (Conv2D)          (None, 14, 14, 64)        36928
_________________________________________________________________
max_pooling2d_63 (MaxPooling (None, 7, 7, 64)          0
_________________________________________________________________
dropout_63 (Dropout)         (None, 7, 7, 64)          0
_________________________________________________________________
conv2d_127 (Conv2D)          (None, 5, 5, 128)         73856
_________________________________________________________________
conv2d_128 (Conv2D)          (None, 3, 3, 128)         147584
_________________________________________________________________
max_pooling2d_64 (MaxPooling (None, 1, 1, 128)         0
```

```
_________________________________________________________________
dropout_64 (Dropout)         (None, 1, 1, 128)         0
_________________________________________________________________
flatten_32 (Flatten)         (None, 128)               0
_________________________________________________________________
dense_63 (Dense)             (None, 512)               66048
_________________________________________________________________
dense_64 (Dense)             (None, 7)                 3591
=================================================================
Total params: 328,647
Trainable params: 328,647
Non-trainable params: 0
_________________________________________________________________
None
Epoch 1/10
28709/28709 [==============================] - 4s 145us/step - loss: 2.1478 - acc: 0.
Epoch 2/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.9520 - acc: 0.2
Epoch 3/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.9378 - acc: 0.2
Epoch 4/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9059 - acc: 0.2
Epoch 5/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.8848 - acc: 0.3
Epoch 6/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.8792 - acc: 0.3
Epoch 7/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.9025 - acc: 0.2
Epoch 8/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.9804 - acc: 0.2
Epoch 9/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.9621 - acc: 0.2
Epoch 10/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9537 - acc: 0.2
3589/3589 [==============================] - 1s 399us/step
Accuracy on Test samples: 0.24965171357339125
Kernel Size: 2
Dropout: 0.3
Model: "sequential_33"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_129 (Conv2D)          (None, 16, 16, 64)        320
_________________________________________________________________
conv2d_130 (Conv2D)          (None, 15, 15, 64)        16448
_________________________________________________________________
max_pooling2d_65 (MaxPooling (None, 7, 7, 64)          0
_________________________________________________________________
dropout_65 (Dropout)         (None, 7, 7, 64)          0
_________________________________________________________________
conv2d_131 (Conv2D)          (None, 6, 6, 128)         32896
_________________________________________________________________
conv2d_132 (Conv2D)          (None, 5, 5, 128)         65664
_________________________________________________________________
max_pooling2d_66 (MaxPooling (None, 2, 2, 128)         0
_________________________________________________________________
dropout_66 (Dropout)         (None, 2, 2, 128)         0
_________________________________________________________________
flatten_33 (Flatten)         (None, 512)               0
_________________________________________________________________
dense_65 (Dense)             (None, 512)               262656
```

```
_________________________________________________________________
dense_66 (Dense)             (None, 7)                 3591
=================================================================
Total params: 381,575
Trainable params: 381,575
Non-trainable params: 0
_________________________________________________________________
None
Epoch 1/10
28709/28709 [==============================] - 4s 146us/step - loss: 2.0020 - acc: 0.
Epoch 2/10
28709/28709 [==============================] - 1s 45us/step - loss: 1.9467 - acc: 0.2
Epoch 3/10
28709/28709 [==============================] - 1s 45us/step - loss: 1.9280 - acc: 0.2
Epoch 4/10
28709/28709 [==============================] - 1s 45us/step - loss: 1.9140 - acc: 0.2
Epoch 5/10
28709/28709 [==============================] - 1s 45us/step - loss: 1.8755 - acc: 0.3
Epoch 6/10
28709/28709 [==============================] - 1s 45us/step - loss: 1.8854 - acc: 0.3
Epoch 7/10
28709/28709 [==============================] - 1s 45us/step - loss: 1.8927 - acc: 0.2
Epoch 8/10
28709/28709 [==============================] - 1s 45us/step - loss: 1.8536 - acc: 0.3
Epoch 9/10
28709/28709 [==============================] - 1s 45us/step - loss: 1.8521 - acc: 0.3
Epoch 10/10
28709/28709 [==============================] - 1s 45us/step - loss: 1.8289 - acc: 0.3
3589/3589 [==============================] - 1s 407us/step
Accuracy on Test samples: 0.3382557815630544
Kernel Size: 3
Dropout: 0.3
Model: "sequential_34"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_133 (Conv2D)          (None, 16, 16, 64)        640
_________________________________________________________________
conv2d_134 (Conv2D)          (None, 14, 14, 64)        36928
_________________________________________________________________
max_pooling2d_67 (MaxPooling (None, 7, 7, 64)          0
_________________________________________________________________
dropout_67 (Dropout)         (None, 7, 7, 64)          0
_________________________________________________________________
conv2d_135 (Conv2D)          (None, 5, 5, 128)         73856
_________________________________________________________________
conv2d_136 (Conv2D)          (None, 3, 3, 128)         147584
_________________________________________________________________
max_pooling2d_68 (MaxPooling (None, 1, 1, 128)         0
_________________________________________________________________
dropout_68 (Dropout)         (None, 1, 1, 128)         0
_________________________________________________________________
flatten_34 (Flatten)         (None, 128)               0
_________________________________________________________________
dense_67 (Dense)             (None, 512)               66048
_________________________________________________________________
dense_68 (Dense)             (None, 7)                 3591
=================================================================
Total params: 328,647
Trainable params: 328,647
Non-trainable params: 0
_________________________________________________________________
```

```
None
Epoch 1/10
28709/28709 [==============================] - 4s 156us/step - loss: 1.9843 - acc: 0.
Epoch 2/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9349 - acc: 0.2
Epoch 3/10
28709/28709 [==============================] - 1s 48us/step - loss: 1.8743 - acc: 0.3
Epoch 4/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.8782 - acc: 0.3
Epoch 5/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.8071 - acc: 0.3
Epoch 6/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.7780 - acc: 0.3
Epoch 7/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.7639 - acc: 0.3
Epoch 8/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.7149 - acc: 0.4
Epoch 9/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.6695 - acc: 0.4
Epoch 10/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.6500 - acc: 0.4
3589/3589 [==============================] - 2s 420us/step
Accuracy on Test samples: 0.45082195598489894
Kernel Size: 2
Dropout: 0.4
Model: "sequential_35"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_137 (Conv2D)          (None, 16, 16, 64)        320
_________________________________________________________________
conv2d_138 (Conv2D)          (None, 15, 15, 64)        16448
_________________________________________________________________
max_pooling2d_69 (MaxPooling (None, 7, 7, 64)          0
_________________________________________________________________
dropout_69 (Dropout)         (None, 7, 7, 64)          0
_________________________________________________________________
conv2d_139 (Conv2D)          (None, 6, 6, 128)         32896
_________________________________________________________________
conv2d_140 (Conv2D)          (None, 5, 5, 128)         65664
_________________________________________________________________
max_pooling2d_70 (MaxPooling (None, 2, 2, 128)         0
_________________________________________________________________
dropout_70 (Dropout)         (None, 2, 2, 128)         0
_________________________________________________________________
flatten_35 (Flatten)         (None, 512)               0
_________________________________________________________________
dense_69 (Dense)             (None, 512)               262656
_________________________________________________________________
dense_70 (Dense)             (None, 7)                 3591
=================================================================
Total params: 381,575
Trainable params: 381,575
Non-trainable params: 0
_________________________________________________________________
None
Epoch 1/10
28709/28709 [==============================] - 4s 157us/step - loss: 3.9552 - acc: 0.
Epoch 2/10
28709/28709 [==============================] - 1s 46us/step - loss: 3.8373 - acc: 0.2
Epoch 3/10
28709/28709 [==============================] - 1s 45us/step - loss: 3.8247 - acc: 0.2
```

```
Epoch 4/10
28709/28709 [==============================] - 1s 45us/step - loss: 3.8246 - acc: 0.2
Epoch 5/10
28709/28709 [==============================] - 1s 45us/step - loss: 3.8046 - acc: 0.2
Epoch 6/10
28709/28709 [==============================] - 1s 44us/step - loss: 3.7788 - acc: 0.3
Epoch 7/10
28709/28709 [==============================] - 1s 45us/step - loss: 3.7734 - acc: 0.3
Epoch 8/10
28709/28709 [==============================] - 1s 45us/step - loss: 3.7678 - acc: 0.3
Epoch 9/10
28709/28709 [==============================] - 1s 45us/step - loss: 3.7833 - acc: 0.3
Epoch 10/10
28709/28709 [==============================] - 1s 46us/step - loss: 3.7560 - acc: 0.3
3589/3589 [==============================] - 2s 445us/step
Accuracy on Test samples: 0.34717191419052723
Kernel Size: 3
Dropout: 0.4
Model: "sequential_36"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_141 (Conv2D)          (None, 16, 16, 64)        640
_________________________________________________________________
conv2d_142 (Conv2D)          (None, 14, 14, 64)        36928
_________________________________________________________________
max_pooling2d_71 (MaxPooling (None, 7, 7, 64)          0
_________________________________________________________________
dropout_71 (Dropout)         (None, 7, 7, 64)          0
_________________________________________________________________
conv2d_143 (Conv2D)          (None, 5, 5, 128)         73856
_________________________________________________________________
conv2d_144 (Conv2D)          (None, 3, 3, 128)         147584
_________________________________________________________________
max_pooling2d_72 (MaxPooling (None, 1, 1, 128)         0
_________________________________________________________________
dropout_72 (Dropout)         (None, 1, 1, 128)         0
_________________________________________________________________
flatten_36 (Flatten)         (None, 128)               0
_________________________________________________________________
dense_71 (Dense)             (None, 512)               66048
_________________________________________________________________
dense_72 (Dense)             (None, 7)                 3591
=================================================================
Total params: 328,647
Trainable params: 328,647
Non-trainable params: 0
_________________________________________________________________
None
Epoch 1/10
28709/28709 [==============================] - 5s 162us/step - loss: 2.0823 - acc: 0.
Epoch 2/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.9556 - acc: 0.2
Epoch 3/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9332 - acc: 0.2
Epoch 4/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.8788 - acc: 0.3
Epoch 5/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.8616 - acc: 0.3
Epoch 6/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9176 - acc: 0.2
```

```
Epoch 7/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.8957 - acc: 0.3
Epoch 8/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.8530 - acc: 0.3
Epoch 9/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.8071 - acc: 0.3
Epoch 10/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.7736 - acc: 0.3
3589/3589 [==============================] - 2s 444us/step
Accuracy on Test samples: 0.41432153804118205
Kernel Size: 2
Dropout: 0.5
Model: "sequential_37"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_145 (Conv2D)          (None, 16, 16, 64)        320
_________________________________________________________________
conv2d_146 (Conv2D)          (None, 15, 15, 64)        16448
_________________________________________________________________
max_pooling2d_73 (MaxPooling (None, 7, 7, 64)          0
_________________________________________________________________
dropout_73 (Dropout)         (None, 7, 7, 64)          0
_________________________________________________________________
conv2d_147 (Conv2D)          (None, 6, 6, 128)         32896
_________________________________________________________________
conv2d_148 (Conv2D)          (None, 5, 5, 128)         65664
_________________________________________________________________
max_pooling2d_74 (MaxPooling (None, 2, 2, 128)         0
_________________________________________________________________
dropout_74 (Dropout)         (None, 2, 2, 128)         0
_________________________________________________________________
flatten_37 (Flatten)         (None, 512)               0
_________________________________________________________________
dense_73 (Dense)             (None, 512)               262656
_________________________________________________________________
dense_74 (Dense)             (None, 7)                 3591
=================================================================
Total params: 381,575
Trainable params: 381,575
Non-trainable params: 0
_________________________________________________________________
None
Epoch 1/10
28709/28709 [==============================] - 5s 169us/step - loss: 2.0850 - acc: 0.
Epoch 2/10
28709/28709 [==============================] - 1s 48us/step - loss: 1.9683 - acc: 0.2
Epoch 3/10
28709/28709 [==============================] - 1s 48us/step - loss: 1.9480 - acc: 0.2
Epoch 4/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9409 - acc: 0.2
Epoch 5/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9328 - acc: 0.2
Epoch 6/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9206 - acc: 0.2
Epoch 7/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.8985 - acc: 0.2
Epoch 8/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.8919 - acc: 0.3
Epoch 9/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.8900 - acc: 0.3
Epoch 10/10
```

```
28709/28709 [==============================] - 1s 46us/step - loss: 1.8610 - acc: 0.3
3589/3589 [==============================] - 2s 465us/step
Accuracy on Test samples: 0.35775982171056264
Kernel Size: 3
Dropout: 0.5
Model: "sequential_38"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_149 (Conv2D)          (None, 16, 16, 64)        640
_________________________________________________________________
conv2d_150 (Conv2D)          (None, 14, 14, 64)        36928
_________________________________________________________________
max_pooling2d_75 (MaxPooling (None, 7, 7, 64)          0
_________________________________________________________________
dropout_75 (Dropout)         (None, 7, 7, 64)          0
_________________________________________________________________
conv2d_151 (Conv2D)          (None, 5, 5, 128)         73856
_________________________________________________________________
conv2d_152 (Conv2D)          (None, 3, 3, 128)         147584
_________________________________________________________________
max_pooling2d_76 (MaxPooling (None, 1, 1, 128)         0
_________________________________________________________________
dropout_76 (Dropout)         (None, 1, 1, 128)         0
_________________________________________________________________
flatten_38 (Flatten)         (None, 128)               0
_________________________________________________________________
dense_75 (Dense)             (None, 512)               66048
_________________________________________________________________
dense_76 (Dense)             (None, 7)                 3591
=================================================================
Total params: 328,647
Trainable params: 328,647
Non-trainable params: 0
_________________________________________________________________
None
Epoch 1/10
28709/28709 [==============================] - 5s 174us/step - loss: 2.1674 - acc: 0.
Epoch 2/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9582 - acc: 0.2
Epoch 3/10
28709/28709 [==============================] - 1s 48us/step - loss: 1.9515 - acc: 0.2
Epoch 4/10
28709/28709 [==============================] - 1s 48us/step - loss: 1.9384 - acc: 0.2
Epoch 5/10
28709/28709 [==============================] - 1s 46us/step - loss: 1.9252 - acc: 0.2
Epoch 6/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9082 - acc: 0.2
Epoch 7/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.8795 - acc: 0.3
Epoch 8/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.8527 - acc: 0.3
Epoch 9/10
28709/28709 [==============================] - 1s 48us/step - loss: 1.9342 - acc: 0.2
Epoch 10/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9389 - acc: 0.2
3589/3589 [==============================] - 2s 493us/step
Accuracy on Test samples: 0.289774310397019
[0.24965171357339125, 0.3700195040567302, 0.2471440512719145, 0.24965171357339125, 0.
```

```
best=(np.argmax(results))
print('Best Feature Pair is: {0} and {1}'.format(featureK[best], featureD[best]))
print("Best performance from training:",results[best])
kSize = featureK[best]
dropout_rate = featureD[best]
common_features = [Conv2D(64, kernel_size=(kSize), strides=3, activation='relu', input_
            Conv2D(64, kernel_size=(kSize), activation='relu'),
            MaxPooling2D(pool_size=(2,2)), Dropout(dropout_rate),
            Conv2D(128, kernel_size=(kSize), activation='relu'),
            Conv2D(128, kernel_size=(kSize), activation='relu'),
            MaxPooling2D(pool_size=(2,2)), Dropout(dropout_rate), Flatten(),]

classifier = [Dense(512, activation='relu'), Dense(7, activation='relu'),]
cnn_model = Sequential(common_features+classifier)
print("Kernel Size: {0} \nDropout: {1}".format(kSize,dropout_rate))
print(cnn_model.summary())
cnn_model.compile(optimizer='adam', loss='categorical_crossentropy',metrics=['accuracy'
# Train model
cnn_model.fit(train_images_3d, to_categorical(train_labels), epochs=10, batch_size=256,

performance = cnn_model.evaluate(test_images_3d, to_categorical(test_labels))
print("Accuracy on Test samples: {0}".format(performance[1]))
```

```
Best Feature Pair is: 3 and 0.3
Best performance from training: 0.45082195598489894
Kernel Size: 3
Dropout: 0.3
Model: "sequential_40"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_157 (Conv2D)          (None, 16, 16, 64)        640       
_________________________________________________________________
conv2d_158 (Conv2D)          (None, 14, 14, 64)        36928     
_________________________________________________________________
max_pooling2d_79 (MaxPooling (None, 7, 7, 64)          0         
_________________________________________________________________
dropout_79 (Dropout)         (None, 7, 7, 64)          0         
_________________________________________________________________
conv2d_159 (Conv2D)          (None, 5, 5, 128)         73856     
_________________________________________________________________
conv2d_160 (Conv2D)          (None, 3, 3, 128)         147584    
_________________________________________________________________
max_pooling2d_80 (MaxPooling (None, 1, 1, 128)         0         
_________________________________________________________________
dropout_80 (Dropout)         (None, 1, 1, 128)         0         
_________________________________________________________________
flatten_40 (Flatten)         (None, 128)               0         
_________________________________________________________________
dense_79 (Dense)             (None, 512)               66048     
_________________________________________________________________
dense_80 (Dense)             (None, 7)                 3591      
=================================================================
Total params: 328,647
Trainable params: 328,647
Non-trainable params: 0
_________________________________________________________________
None
Epoch 1/10
28709/28709 [==============================] - 5s 182us/step - loss: 1.9924 - acc: 0.
Epoch 2/10
28709/28709 [==============================] - 1s 48us/step - loss: 1.9631 - acc: 0.2
Epoch 3/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9470 - acc: 0.2
Epoch 4/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9074 - acc: 0.2
Epoch 5/10
28709/28709 [==============================] - 1s 48us/step - loss: 1.8598 - acc: 0.3
Epoch 6/10
28709/28709 [==============================] - 1s 48us/step - loss: 1.8313 - acc: 0.3
Epoch 7/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9253 - acc: 0.2
Epoch 8/10
28709/28709 [==============================] - 1s 47us/step - loss: 1.9469 - acc: 0.2
Epoch 9/10
28709/28709 [==============================] - 1s 49us/step - loss: 1.8832 - acc: 0.3
Epoch 10/10
28709/28709 [==============================] - 1s 48us/step - loss: 1.8336 - acc: 0.3
3589/3589 [==============================] - 2s 522us/step
Accuracy on Test samples: 0.2449150181191982
```

```
def optimize_cnn(hyperparameter):

  # Define model using hyperparameters
  cnn_model = Sequential([Conv2D(32, kernel_size=hyperparameter['conv_kernel_size'], ac
            Conv2D(32, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
            MaxPooling2D(pool_size=(2,2)), Dropout(hyperparameter['dropout_prob']),
            Conv2D(64, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
            Conv2D(64, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
            MaxPooling2D(pool_size=(2,2)), Dropout(hyperparameter['dropout_prob']),
            Flatten(),
            Dense(512, activation='relu'),
            Dense(7, activation='softmax'),])

  cnn_model.compile(optimizer=hyperparameter['optimizer'], loss='categorical_crossentro
  time_callback = TimeHistory()
  hist = cnn_model.fit(train_images_3d, to_categorical(train_labels), epochs=10, batch_
  # print(hist.history.accuracy)
  print("Total Training Time is (s): ", sum(time_callback.times))
  # Evaluate accuracy on validation data
  performance = cnn_model.evaluate(valid_images_3d, to_categorical(valid_labels), verbo

  print("Hyperparameters: ", hyperparameter, "Accuracy: ", performance[1])
  print("---------------------------------------------------")
  # We want to minimize loss i.e. negative of accuracy
  return({"status": STATUS_OK, "loss": -1*performance[1], "model":cnn_model})


# Define search space for hyper-parameters
space = {
    # The kernel_size for convolutions:
    'conv_kernel_size': hp.choice('conv_kernel_size', [1, 3, 5]),
    # Uniform distribution in finding appropriate dropout values
    'dropout_prob': hp.uniform('dropout_prob', 0.1, 0.35),
    # Choice of optimizer
    'optimizer': hp.choice('optimizer', ['Adam', 'sgd']),
}

trials = Trials()

# Find the best hyperparameters
best = fmin(
        optimize_cnn,
        space,
        algo=tpe.suggest,
        trials=trials,
        max_evals=25,
    )

print("==================================")
print("Best Hyperparameters", best)

# You can retrain the final model with optimal hyperparameters on train+validation data

# Or you can use the model returned directly
# Find trial which has minimum loss value and use that model to perform evaluation on t
```

```
# Find trial which has minimum loss value and use that model to perform evaluation on t
test_model = trials.results[np.argmin([r['loss'] for r in trials.results])]['model']

performance = test_model.evaluate(test_images_3d, to_categorical(test_labels))

print("==================================")
print("Test Accuracy: ", performance[1])
```

```
Total Training Time is (s):
28.2460458278656
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.14668735307891242, 'optimizer': 'sgd'}
Accuracy:
0.3399275564265537
----------------------------------------------------
Total Training Time is (s):
23.3261399269104
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.17386172811548062, 'optimizer': 'sgd'}
Accuracy:
0.3265533575144077
----------------------------------------------------
Total Training Time is (s):
29.898162126541138
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.16029133971157797, 'optimizer': 'Adam'}
Accuracy:
0.5770409585174726
----------------------------------------------------
Total Training Time is (s):
28.340755224227905
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.19075674893547134, 'optimizer': 'sgd'}
Accuracy:
0.3558094176692397
----------------------------------------------------
Total Training Time is (s):
28.23865532875061
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.2915313031622959, 'optimizer': 'sgd'}
Accuracy:
0.3349122318236002
----------------------------------------------------
Total Training Time is (s):
29.37062120437622
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.34814906012233493, 'optimizer': 'Adam'}
Accuracy:
0.5884647534464222
----------------------------------------------------
Total Training Time is (s):
29.427371740341187
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.12730390537713165, 'optimizer': 'Adam'}
Accuracy:
0.5795486208189494
----------------------------------------------------
Total Training Time is (s):
23.43778681755066
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.2914162541212033, 'optimizer': 'sgd'}
Accuracy:
0.32683198663410484
----------------------------------------------------
Total Training Time is (s):
23.60374140739441
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.23456208751505514, 'optimizer': 'sgd'}
Accuracy:
```

```
0.3413207021786596
----------------------------------------------------
Total Training Time is (s):
25.58343744277954
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.21816456764498765, 'optimizer': 'Adam'}
Accuracy:
0.4611312343312625
----------------------------------------------------
 40%|████      | 10/25 [04:58<07:27, 29.83s/it, best loss: -0.5884647534464222]
---------------------------------------------------------------------------
KeyboardInterrupt                         Traceback (most recent call last)
<ipython-input-18-dd4c7d03b67d> in <module>()
     44         algo=tpe.suggest,
     45         trials=trials,
---> 46         max_evals=25,
     47     )
     48

12 frames

/tensorflow-1.15.0/python3.6/tensorflow_core/python/client/session.py in __call__(sel
   1470         ret = tf_session.TF_SessionRunCallable(self._session._session,
   1471                                                self._handle, args,
-> 1472                                                run_metadata_ptr)
   1473         if run_metadata:
   1474           proto_data = tf_session.TF_GetBuffer(run_metadata_ptr)

KeyboardInterrupt:
```

SEARCH STACK OVERFLOW

FINE TUNING

```
from keras.datasets import mnist
from keras.models import Model
from keras.layers import Input
 #Load MNISt dataset
(train_imagesf, train_labelsf), (test_imagesf, test_labelsf) = mnist.load_data()
train_imagesf = (train_imagesf / 255) - 0.5
test_imagesf = (test_imagesf / 255) - 0.5
```

```
Downloading data from https://s3.amazonaws.com/img-datasets/mnist.npz
11493376/11490434 [==============================] - 0s 0us/step
```

```
train_images_3df = train_imagesf.reshape(60000,28,28,1)
test_images_3df = test_imagesf.reshape(10000,28,28,1)
train_images_3df = train_images_3df[:28709]
train_labelsf = train_labelsf[:28709]
test_images_3df = test_images_3df[:3589]
test_labelsf = test_labelsf[:3589]

```

```
Base_feature_model = Sequential([Conv2D(32, kernel_size=3, activation='relu'),
            Conv2D(32, kernel_size=3, activation='relu'),
            MaxPooling2D(pool_size=(2,2)), Dropout(0.25),
            Conv2D(64, kernel_size=3, activation='relu'),
            Conv2D(64, kernel_size=3, activation='relu'),
            MaxPooling2D(pool_size=(2,2)), Dropout(0.25),
            Dense(512, activation='relu'), Flatten(),])

# Define task-specific classifiation layers
Classifier_mnist = Dense(10, activation='softmax', name='MNIST')
Classifier_fer = Dense(7, activation='softmax', name='FER')

# Instantiate a Tensor to feed Input (Input Layer)
mnist_input = Input(shape=(28,28,1))
fer_input = Input(shape=(48,48,1))

# Call Base_feature_model over the mnist images
mnist_features = Base_feature_model(mnist_input)

# Call Base_feature_model over the fashion-mnist images
fer_features = Base_feature_model(fer_input)

# Call mnist_prediction layer over the mnist images
# mnist_prediction represents the predicted output for mnist dataset
mnist_prediction = Classifier_mnist(mnist_features)

# Call fashion_mnist_prediction layer over the mnist images
# fashion_mnist_prediction represents the predicted output for fashion-mnist dataset
fer_prediction = Classifier_fer(fer_features)


joint_model = Model(inputs=[mnist_input, fer_input],
                    outputs=[mnist_prediction, fer_prediction])

print(joint_model.summary())

joint_model.compile(optimizer='adam', loss='binary_crossentropy',metrics=['accuracy'],)

joint_model.fit([train_images_3df, train_images_3d],
                [to_categorical(train_labelsf), to_categorical(train_labels)],
                epochs=2, batch_size=1024,)
performance = joint_model.evaluate([test_images_3df, valid_images_3d],
                                   [to_categorical(test_labelsf),
                                    to_categorical(valid_labels)], verbose=1)

print("===\nMNIST Accuracy: {0}\nFER Accuracy: {1}".format(performance[3], performance[
performance = joint_model.evaluate([test_images_3df, test_images_3d],
                                   [to_categorical(test_labelsf),
                                    to_categorical(test_labels)], verbose=1)

print("===\nMNIST Accuracy: {0}\nFER Accuracy: {1}".format(performance[3], performance[
```

```
Model: "model_1"
__________________________________________________________________________________________________
Layer (type)                    Output Shape         Param #     Connected to
==================================================================================================
input_1 (InputLayer)            (None, 28, 28, 1)    0
__________________________________________________________________________________________________
input_2 (InputLayer)            (None, 48, 48, 1)    0
__________________________________________________________________________________________________
sequential_2 (Sequential)       multiple             98272       input_1[0][0]
                                                                 input_2[0][0]
__________________________________________________________________________________________________
MNIST (Dense)                   (None, 10)           81930       sequential_2[1][0]
__________________________________________________________________________________________________
FER (Dense)                     (None, 7)            290311      sequential_2[2][0]
==================================================================================================
Total params: 470,513
Trainable params: 470,513
Non-trainable params: 0
__________________________________________________________________________________________________
None
WARNING:tensorflow:From /tensorflow-1.15.0/python3.6/tensorflow_core/python/ops/nn_im
Instructions for updating:
Use tf.where in 2.0, which has the same broadcast rule as np.where
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorfl

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorfl

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorfl

Epoch 1/2
WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorfl

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorfl

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorfl

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorfl

WARNING:tensorflow:From /usr/local/lib/python3.6/dist-packages/keras/backend/tensorfl

28709/28709 [==============================] - 18s 611us/step - loss: 0.5884 - MNIST_
Epoch 2/2
28709/28709 [==============================] - 3s 116us/step - loss: 0.4026 - MNIST_l
3589/3589 [==============================] - 1s 209us/step
===
MNIST Accuracy: 0.9875731395127282
FER Accuracy: 0.8647852702936644
3589/3589 [==============================] - 1s 145us/step
===
MNIST Accuracy: 0.9875731395127282
FER Accuracy: 0.8625562360739103
```

Fine tuning using the MNIST Model.

```
import cv2
from skimage.transform import resize
# Resizing the images.
flatten_train_images = train_image_array.reshape((-1, 48,48))
flatten_test_images = test_image_array.reshape((-1, 48,48))
flatten_valid_images = valid_image_array.reshape((-1,48,48))
resized_images_train = []
resized_images_test = []
resized_images_valid = []
# for i in range(len(flatten_test_images)):
for i in range(len(train_pixels)):
  img = flatten_train_images[i]
  img=cv2.resize(img, dsize=(28,28),interpolation=cv2.INTER_CUBIC)
  resized_images_train.append(img)
resized_images_train = np.array(resized_images_train)

for i in range(len(valid_pixels)):
  img = flatten_valid_images[i]
  img=cv2.resize(img, dsize=(28,28),interpolation=cv2.INTER_CUBIC)
  resized_images_valid.append(img)
resized_images_valid = np.array(resized_images_valid)


for i in range(len(test_pixels)):
  img = flatten_test_images[i]
  img=cv2.resize(img, dsize=(28,28),interpolation=cv2.INTER_CUBIC)
  resized_images_test.append(img)
resized_images_test = np.array(resized_images_test)

```

```
from keras.layers import Conv2D, Flatten, MaxPooling2D

# Define 2 groups of layers: features layer (convolutions) and classification layer
common_features = [Conv2D(32, kernel_size=3, activation='relu', input_shape=(28,28,1)),
            Conv2D(32, kernel_size=3, activation='relu'),
            MaxPooling2D(pool_size=(2,2)), Dropout(0.25),
            Conv2D(64, kernel_size=3, activation='relu'),
            Conv2D(64, kernel_size=3, activation='relu'),
            MaxPooling2D(pool_size=(2,2)), Dropout(0.25), Flatten(),]
classifier = [Dense(512, activation='relu'), Dense(10, activation='softmax'),]

cnn_model = Sequential(common_features+classifier)

print(cnn_model.summary())  # Compare number of parameteres against FFN
cnn_model.compile(optimizer='adam', loss='categorical_crossentropy',metrics=['accuracy'

train_images_3df = train_imagesf.reshape(60000,28,28,1)
test_images_3df = test_imagesf.reshape(10000,28,28,1)

cnn_model.fit(train_images_3df, to_categorical(train_labelsf), epochs=10, batch_size=25
performance = cnn_model.evaluate(test_images_3df, to_categorical(test_labelsf))

print("Accuracy on Test samples: {0}".format(performance[1]))
```

```
Model: "sequential_29"
_________________________________________________________________
Layer (type)                 Output Shape              Param #
=================================================================
conv2d_9 (Conv2D)            (None, 26, 26, 32)        320
_________________________________________________________________
conv2d_10 (Conv2D)           (None, 24, 24, 32)        9248
_________________________________________________________________
max_pooling2d_5 (MaxPooling2 (None, 12, 12, 32)        0
_________________________________________________________________
dropout_31 (Dropout)         (None, 12, 12, 32)        0
_________________________________________________________________
conv2d_11 (Conv2D)           (None, 10, 10, 64)        18496
_________________________________________________________________
conv2d_12 (Conv2D)           (None, 8, 8, 64)          36928
_________________________________________________________________
max_pooling2d_6 (MaxPooling2 (None, 4, 4, 64)          0
_________________________________________________________________
dropout_32 (Dropout)         (None, 4, 4, 64)          0
_________________________________________________________________
flatten_3 (Flatten)          (None, 1024)              0
_________________________________________________________________
dense_31 (Dense)             (None, 512)               524800
_________________________________________________________________
dense_32 (Dense)             (None, 10)                5130
=================================================================
Total params: 594,922
Trainable params: 594,922
Non-trainable params: 0
_________________________________________________________________
None
Epoch 1/10
60000/60000 [==============================] - 9s 145us/step - loss: 0.2772 - acc: 0.
Epoch 2/10
60000/60000 [==============================] - 2s 39us/step - loss: 0.0598 - acc: 0.9
Epoch 3/10
60000/60000 [==============================] - 2s 39us/step - loss: 0.0429 - acc: 0.9
Epoch 4/10
60000/60000 [==============================] - 2s 39us/step - loss: 0.0336 - acc: 0.9
Epoch 5/10
60000/60000 [==============================] - 2s 39us/step - loss: 0.0272 - acc: 0.9
Epoch 6/10
60000/60000 [==============================] - 2s 39us/step - loss: 0.0242 - acc: 0.9
Epoch 7/10
60000/60000 [==============================] - 2s 39us/step - loss: 0.0209 - acc: 0.9
Epoch 8/10
60000/60000 [==============================] - 2s 38us/step - loss: 0.0188 - acc: 0.9
Epoch 9/10
60000/60000 [==============================] - 2s 38us/step - loss: 0.0160 - acc: 0.9
Epoch 10/10
60000/60000 [==============================] - 2s 39us/step - loss: 0.0148 - acc: 0.9
10000/10000 [==============================] - 1s 124us/step
Accuracy on Test samples: 0.9944
```

```
for l in common_features:
  l.trainable = False

```

```
classifier2 = [Dense(512, activation='relu'), Dense(7, activation='softmax'),]

cnn_model.add(Dense(7,activation='softmax'))
print(cnn_model.summary())
resized_images_valid_3d = resized_images_valid.reshape(3589,28,28,1)
resized_images_train_3d = resized_images_train.reshape(28709,28,28,1)
cnn_model.compile(optimizer='adam', loss='categorical_crossentropy',metrics=['accuracy'

cnn_model.fit(resized_images_train_3d, to_categorical(train_labels), epochs=8, batch_si
performance = cnn_model.evaluate(resized_images_valid_3d, to_categorical(valid_labels))

print("Accuracy on Test samples: {0}".format(performance[1]))
```

```
Model: "sequential_29"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
conv2d_9 (Conv2D)            (None, 26, 26, 32)        320       
_________________________________________________________________
conv2d_10 (Conv2D)           (None, 24, 24, 32)        9248      
_________________________________________________________________
max_pooling2d_5 (MaxPooling2 (None, 12, 12, 32)        0         
_________________________________________________________________
dropout_31 (Dropout)         (None, 12, 12, 32)        0         
_________________________________________________________________
conv2d_11 (Conv2D)           (None, 10, 10, 64)        18496     
_________________________________________________________________
conv2d_12 (Conv2D)           (None, 8, 8, 64)          36928     
_________________________________________________________________
max_pooling2d_6 (MaxPooling2 (None, 4, 4, 64)          0         
_________________________________________________________________
dropout_32 (Dropout)         (None, 4, 4, 64)          0         
_________________________________________________________________
flatten_3 (Flatten)          (None, 1024)              0         
_________________________________________________________________
dense_31 (Dense)             (None, 512)               524800    
_________________________________________________________________
dense_32 (Dense)             (None, 10)                5130      
_________________________________________________________________
dense_35 (Dense)             (None, 7)                 77        
=================================================================
Total params: 659,914
Trainable params: 594,922
Non-trainable params: 64,992
_________________________________________________________________
None
Epoch 1/8
28709/28709 [==============================] - 2s 76us/step - loss: 1.8593 - acc: 0.2
Epoch 2/8
28709/28709 [==============================] - 1s 23us/step - loss: 1.7825 - acc: 0.2
Epoch 3/8
28709/28709 [==============================] - 1s 25us/step - loss: 1.7408 - acc: 0.3
Epoch 4/8
28709/28709 [==============================] - 1s 25us/step - loss: 1.7033 - acc: 0.3
Epoch 5/8
28709/28709 [==============================] - 1s 23us/step - loss: 1.6698 - acc: 0.3
Epoch 6/8
28709/28709 [==============================] - 1s 24us/step - loss: 1.6397 - acc: 0.3
Epoch 7/8
28709/28709 [==============================] - 1s 24us/step - loss: 1.6091 - acc: 0.3
Epoch 8/8
28709/28709 [==============================] - 1s 24us/step - loss: 1.5825 - acc: 0.4
3589/3589 [==============================] - 1s 232us/step
Accuracy on Test samples: 0.4093062134299248
```

Data Augmentation

```
1 from keras.preprocessing.image import ImageDataGenerator
```

```
from matplotlib import pyplot
datagen = ImageDataGenerator()

#feature standardization
x_train = (train_image_array)
x_valid = (valid_image_array)
x_test = (test_image_array)

x_train = x_train.reshape((x_train.shape[0], 48, 48, 1))
x_valid = x_valid.reshape((x_valid.shape[0], 48, 48, 1))
x_test = x_test.reshape((x_valid.shape[0], 48, 48, 1))

x_train = x_train.astype('float32')
x_valid = x_valid.astype('float32')
x_test = x_test.astype('float32')

datagen = ImageDataGenerator(featurewise_center=True, featurewise_std_normalization=Tru
datagen.fit(x_train)
datagen.fit(x_valid)
datagen.fit(x_test)
```

```
def optimize_cnn(hyperparameter):

  # Define model using hyperparameters
  cnn_model = Sequential([Conv2D(32, kernel_size=hyperparameter['conv_kernel_size'], ac
            Conv2D(32, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
            MaxPooling2D(pool_size=(2,2)), Dropout(hyperparameter['dropout_prob']),
            Conv2D(64, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
            Conv2D(64, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
            MaxPooling2D(pool_size=(2,2)), Dropout(hyperparameter['dropout_prob']),
            Flatten(),
            Dense(512, activation='relu'),
            Dense(7, activation='softmax'),])

  cnn_model.compile(optimizer=hyperparameter['optimizer'], loss='categorical_crossentro
  time_callback = TimeHistory()
  hist = cnn_model.fit(x_train, to_categorical(train_labels), epochs=10, batch_size=256
  # print(hist.history.accuracy)
  print("Total Training Time is (s): ", sum(time_callback.times))
  # Evaluate accuracy on validation data
  performance = cnn_model.evaluate(x_valid, to_categorical(valid_labels), verbose=0)

  print("Hyperparameters: ", hyperparameter, "Accuracy: ", performance[1])
  print("---------------------------------------------------")
  # We want to minimize loss i.e. negative of accuracy
  return({"status": STATUS_OK, "loss": -1*performance[1], "model":cnn_model})


# Define search space for hyper-parameters
space = {
    # The kernel_size for convolutions:
    'conv_kernel_size': hp.choice('conv_kernel_size', [1, 3, 5]),
    # Uniform distribution in finding appropriate dropout values
    'dropout_prob': hp.uniform('dropout_prob', 0.1, 0.35),
    # Choice of optimizer
```

```
    # Choice of optimizer
    'optimizer': hp.choice('optimizer', ['Adam', 'sgd']),
}

trials = Trials()

# Find the best hyperparameters
best = fmin(
        optimize_cnn,
        space,
        algo=tpe.suggest,
        trials=trials,
        max_evals=25,
    )

print("==================================")
print("Best Hyperparameters", best)

# You can retrain the final model with optimal hyperparameters on train+validation dat

# Or you can use the model returned directly
# Find trial which has minimum loss value and use that model to perform evaluation on t
test_model = trials.results[np.argmin([r['loss'] for r in trials.results])]['model']

performance = test_model.evaluate(x_test, to_categorical(test_labels))

print("==================================")
print("Test Accuracy: ", performance[1])
```

```
Total Training Time is (s):
26.69492268562317
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.2542249469349509, 'optimizer': 'Adam'}
Accuracy:
0.5856784619754255
----------------------------------------------------
Total Training Time is (s):
26.36576533317566
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.1339069129108087, 'optimizer': 'Adam'}
Accuracy:
0.5881861242727504
----------------------------------------------------
Total Training Time is (s):
25.207025289535522
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.18646617942102145, 'optimizer': 'sgd'}
Accuracy:
0.3290610197868212
----------------------------------------------------
Total Training Time is (s):
25.25748372077942
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.2422444255685212, 'optimizer': 'sgd'}
Accuracy:
0.33630537754664286
----------------------------------------------------
Total Training Time is (s):
25.461172342300415
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.2448541881379686, 'optimizer': 'sgd'}
Accuracy:
0.31930899972552274
----------------------------------------------------
Total Training Time is (s):
26.484083890914917
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.18503897577787976, 'optimizer': 'Adam'}
Accuracy:
0.5792699916494295
----------------------------------------------------
Total Training Time is (s):
26.643880128860474
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.32063192160086557, 'optimizer': 'Adam'}
Accuracy:
0.590136528289162
----------------------------------------------------
Total Training Time is (s):
27.22426700592041
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.13249574191657534, 'optimizer': 'Adam'}
Accuracy:
0.5859570911200341
----------------------------------------------------
Total Training Time is (s):
26.097631216049194
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.29590396234361205, 'optimizer': 'sgd'}
Accuracy:
```

```
0.33769852327383737
----------------------------------------------------
Total Training Time is (s):
26.8969247341156
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.21040384851779753, 'optimizer': 'Adam'}
Accuracy:
0.5951518529170269
----------------------------------------------------
Total Training Time is (s):
27.601470947265625
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.11880611138425023, 'optimizer': 'Adam'}
Accuracy:
0.5820562830913628
----------------------------------------------------
Total Training Time is (s):
23.013309955596924
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.14665198365052354, 'optimizer': 'Adam'}
Accuracy:
0.46308163833937027
----------------------------------------------------
Total Training Time is (s):
26.464831113815308
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.18015588988489312, 'optimizer': 'sgd'}
Accuracy:
0.3134577876928956
----------------------------------------------------
Total Training Time is (s):
26.698853969573975
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.2799730869754218, 'optimizer': 'sgd'}
Accuracy:
0.309835608804681
----------------------------------------------------
Total Training Time is (s):
23.167685508728027
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.160008848531309, 'optimizer': 'Adam'}
Accuracy:
0.4611312343312625
----------------------------------------------------
Total Training Time is (s):
26.600367546081543
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.16467814646642104, 'optimizer': 'sgd'}
Accuracy:
0.30342713848283676
----------------------------------------------------
Total Training Time is (s):
26.676040172576904
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.34563440284244595, 'optimizer': 'sgd'}
Accuracy:
0.30203399275979415
----------------------------------------------------
Total Training Time is (s):
27.901010513305664
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.26596686122277424, 'optimizer': 'Adam'}
```

```
{'conv_kernel_size': 5, 'dropout_prob': 0.20990080122277424, 'optimizer': 'Adam'}
Accuracy:
0.5890220117356393
----------------------------------------------------
Total Training Time is (s):
27.972566843032837
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.1641466973375958, 'optimizer': 'Adam'}
Accuracy:
0.5817776539758176
----------------------------------------------------
Total Training Time is (s):
28.094647645950317
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.3380391316682997, 'optimizer': 'Adam'}
Accuracy:
0.573697408753107
----------------------------------------------------
Total Training Time is (s):
23.941020727157593
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.2156736105684234, 'optimizer': 'Adam'}
Accuracy:
0.45082195598074704
----------------------------------------------------
Total Training Time is (s):
24.138392686843872
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.30311341285267246, 'optimizer': 'Adam'}
Accuracy:
0.4522151017037897
----------------------------------------------------
Total Training Time is (s):
28.54242205619812
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.31859347865493814, 'optimizer': 'Adam'}
Accuracy:
0.584285316248231
----------------------------------------------------
Total Training Time is (s):
28.73721957206726
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.2100158958151668, 'optimizer': 'Adam'}
Accuracy:
0.590136528289162
----------------------------------------------------
Total Training Time is (s):
28.72278118133545
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.2108128237693697, 'optimizer': 'Adam'}
Accuracy:
0.5759264419390385
----------------------------------------------------
100%|██████████| 25/25 [11:48<00:00, 28.32s/it, best loss: -0.5951518529170269]
==================================
Best Hyperparameters {'conv_kernel_size': 2, 'dropout_prob': 0.21040384851779753, 'op
3589/3589 [==============================] - 0s 92us/step
==================================
Test Accuracy:  0.6032320980816108
```

```
# ZCA Whitening
from keras.preprocessing.image import ImageDataGenerator
from matplotlib import pyplot
datagen = ImageDataGenerator()

#feature standardization
x_train = (train_image_array)
x_valid = (valid_image_array)
x_test = (test_image_array)

x_train = x_train.reshape((x_train.shape[0], 48, 48, 1))
x_valid = x_valid.reshape((x_valid.shape[0], 48, 48, 1))
x_test = x_test.reshape((x_valid.shape[0], 48, 48, 1))

x_train = x_train.astype('float32')
x_valid = x_valid.astype('float32')
x_test = x_test.astype('float32')

datagen = ImageDataGenerator(zca_whitening=True)
datagen.fit(x_train)
datagen.fit(x_valid)
datagen.fit(x_test)
```

```
def optimize_cnn(hyperparameter):

  # Define model using hyperparameters
  cnn_model = Sequential([Conv2D(32, kernel_size=hyperparameter['conv_kernel_size'], ac
            Conv2D(32, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
            MaxPooling2D(pool_size=(2,2)), Dropout(hyperparameter['dropout_prob']),
            Conv2D(64, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
            Conv2D(64, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
            MaxPooling2D(pool_size=(2,2)), Dropout(hyperparameter['dropout_prob']),
            Flatten(),
            Dense(512, activation='relu'),
            Dense(7, activation='softmax'),])

  cnn_model.compile(optimizer=hyperparameter['optimizer'], loss='categorical_crossentro
  time_callback = TimeHistory()
  hist = cnn_model.fit(x_train, to_categorical(train_labels), epochs=10, batch_size=256
  # print(hist.history.accuracy)
  print("Total Training Time is (s): ", sum(time_callback.times))
  # Evaluate accuracy on validation data
  performance = cnn_model.evaluate(x_valid, to_categorical(valid_labels), verbose=0)

  print("Hyperparameters: ", hyperparameter, "Accuracy: ", performance[1])
  print("---------------------------------------------------")
  # We want to minimize loss i.e. negative of accuracy
  return({"status": STATUS_OK, "loss": -1*performance[1], "model":cnn_model})

```

```
# Define search space for hyper-parameters
space = {
    # The kernel_size for convolutions:
    'conv_kernel_size': hp.choice('conv_kernel_size', [1, 3, 5]),
    # Uniform distribution in finding appropriate dropout values
    'dropout_prob': hp.uniform('dropout_prob', 0.1, 0.35),
    # Choice of optimizer
    'optimizer': hp.choice('optimizer', ['Adam', 'sgd']),
}

trials = Trials()

# Find the best hyperparameters
best = fmin(
        optimize_cnn,
        space,
        algo=tpe.suggest,
        trials=trials,
        max_evals=25,
    )

print("==================================")
print("Best Hyperparameters", best)

# You can retrain the final model with optimal hyperparameters on train+validation data

# Or you can use the model returned directly
# Find trial which has minimum loss value and use that model to perform evaluation on t
test_model = trials.results[np.argmin([r['loss'] for r in trials.results])]['model']

performance = test_model.evaluate(x_test, to_categorical(test_labels))

print("==================================")
print("Test Accuracy: ", performance[1])
```

```
Total Training Time is (s):
28.13971781730652
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.24814050988778366, 'optimizer': 'sgd'}
Accuracy:
0.34912231820278694
----------------------------------------------------
Total Training Time is (s):
29.38590717315674
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.25791132899874547, 'optimizer': 'Adam'}
Accuracy:
0.574811925335693
----------------------------------------------------
Total Training Time is (s):
25.396419286727905
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.22730878575841162, 'optimizer': 'Adam'}
Accuracy:
0.4413485650640572
----------------------------------------------------
Total Training Time is (s):
23.52994656562805
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.3356007393482103, 'optimizer': 'sgd'}
Accuracy:
0.3170799665977178
----------------------------------------------------
Total Training Time is (s):
28.708142280578613
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.11560059994968835, 'optimizer': 'sgd'}
Accuracy:
0.3455001393187242
----------------------------------------------------
Total Training Time is (s):
25.343907117843628
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.1569881114299798, 'optimizer': 'Adam'}
Accuracy:
0.45555865143909197
----------------------------------------------------
Total Training Time is (s):
23.794260263442993
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.14529594832766432, 'optimizer': 'sgd'}
Accuracy:
0.3232098077500421
----------------------------------------------------
Total Training Time is (s):
29.731204509735107
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.14865966844802445, 'optimizer': 'Adam'}
Accuracy:
0.5959877403508524
----------------------------------------------------
Total Training Time is (s):
29.16386127471924
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.1668994273753261, 'optimizer': 'sgd'}
Accuracy:
```

```
0.29757592644190584
-----------------------------------------------------
Total Training Time is (s):
24.0995192527771
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.34520159231583475, 'optimizer': 'sgd'}
Accuracy:
0.3037057676274453
-----------------------------------------------------
Total Training Time is (s):
25.988826990127563
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.11260333076964793, 'optimizer': 'Adam'}
Accuracy:
0.44552800223733696
-----------------------------------------------------
Total Training Time is (s):
24.36750626564026
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.10067291427456249, 'optimizer': 'sgd'}
Accuracy:
0.3240456951838677
-----------------------------------------------------
Total Training Time is (s):
29.36147117614746
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.3329262177643334, 'optimizer': 'sgd'}
Accuracy:
0.31707996656865456
-----------------------------------------------------
Total Training Time is (s):
24.480132341384888
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.2987819312451138, 'optimizer': 'sgd'}
Accuracy:
0.29311786013647323
-----------------------------------------------------
Total Training Time is (s):
30.930524110794067
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.1979817749585424, 'optimizer': 'Adam'}
Accuracy:
0.5812203956616891
-----------------------------------------------------
Total Training Time is (s):
29.91033911705017
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.1050616079800136, 'optimizer': 'sgd'}
Accuracy:
0.35218723879348074
-----------------------------------------------------
Total Training Time is (s):
29.913865327835083
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.1531927927777971, 'optimizer': 'sgd'}
Accuracy:
0.29172471440512676
-----------------------------------------------------
Total Training Time is (s):
30.116098642349243
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.16843832400704467, 'optimizer': 'sgd'}
```

```
{'conv_kernel_size': 3, 'dropout_prob': 0.10843892460704467, 'optimizer': 'sgd'}
Accuracy:
0.3507940930787419
----------------------------------------------------
Total Training Time is (s):
30.94815754890442
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.15462614464529809, 'optimizer': 'Adam'}
Accuracy:
0.5876288660125967
----------------------------------------------------
Total Training Time is (s):
30.283236026763916
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.11775894597544814, 'optimizer': 'sgd'}
Accuracy:
0.2942323767149073
----------------------------------------------------
Total Training Time is (s):
31.25113534927368
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.1959757796377455, 'optimizer': 'Adam'}
Accuracy:
0.5748119253315411
----------------------------------------------------
Total Training Time is (s):
31.228559494018555
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.1930187501789366, 'optimizer': 'Adam'}
Accuracy:
0.5912510448634442
----------------------------------------------------
Total Training Time is (s):
31.54096746444702
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.19116528768022692, 'optimizer': 'Adam'}
Accuracy:
0.5834494288185573
----------------------------------------------------
Total Training Time is (s):
31.804988145828247
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.22138591652886783, 'optimizer': 'Adam'}
Accuracy:
0.577598216790082
----------------------------------------------------
Total Training Time is (s):
31.88996720314026
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.13687584560602467, 'optimizer': 'Adam'}
Accuracy:
0.5851212037111199
----------------------------------------------------
100%|██████████| 25/25 [13:03<00:00, 31.35s/it, best loss: -0.5959877403508524]
==================================
Best Hyperparameters {'conv_kernel_size': 2, 'dropout_prob': 0.14865966844802445, 'op
3589/3589 [==============================] - 0s 112us/step
==================================
Test Accuracy:  0.5918083031568131
```

```
# Random Rotations
from keras.preprocessing.image import ImageDataGenerator
from matplotlib import pyplot
datagen = ImageDataGenerator()

#feature standardization
x_train = (train_image_array)
x_valid = (valid_image_array)
x_test = (test_image_array)

x_train = x_train.reshape((x_train.shape[0], 48, 48, 1))
x_valid = x_valid.reshape((x_valid.shape[0], 48, 48, 1))
x_test = x_test.reshape((x_valid.shape[0], 48, 48, 1))

x_train = x_train.astype('float32')
x_valid = x_valid.astype('float32')
x_test = x_test.astype('float32')

datagen = ImageDataGenerator(rotation_range=90)
datagen.fit(x_train)
datagen.fit(x_valid)
datagen.fit(x_test)
```

```
def optimize_cnn(hyperparameter):

  # Define model using hyperparameters
  cnn_model = Sequential([Conv2D(32, kernel_size=hyperparameter['conv_kernel_size'], ac
            Conv2D(32, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
            MaxPooling2D(pool_size=(2,2)), Dropout(hyperparameter['dropout_prob']),
            Conv2D(64, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
            Conv2D(64, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
            MaxPooling2D(pool_size=(2,2)), Dropout(hyperparameter['dropout_prob']),
            Flatten(),
            Dense(512, activation='relu'),
            Dense(7, activation='softmax'),])

  cnn_model.compile(optimizer=hyperparameter['optimizer'], loss='categorical_crossentro
  time_callback = TimeHistory()
  hist = cnn_model.fit(x_train, to_categorical(train_labels), epochs=10, batch_size=256
  # print(hist.history.accuracy)
  print("Total Training Time is (s): ", sum(time_callback.times))
  # Evaluate accuracy on validation data
  performance = cnn_model.evaluate(x_valid, to_categorical(valid_labels), verbose=0)

  print("Hyperparameters: ", hyperparameter, "Accuracy: ", performance[1])
  print("------------------------------------------------")
  # We want to minimize loss i.e. negative of accuracy
  return({"status": STATUS_OK, "loss": -1*performance[1], "model":cnn_model})

```

```
# Define search space for hyper-parameters
space = {
    # The kernel_size for convolutions:
    'conv_kernel_size': hp.choice('conv_kernel_size', [1, 3, 5]),
    # Uniform distribution in finding appropriate dropout values
    'dropout_prob': hp.uniform('dropout_prob', 0.1, 0.35),
    # Choice of optimizer
    'optimizer': hp.choice('optimizer', ['Adam', 'sgd']),
}

trials = Trials()

# Find the best hyperparameters
best = fmin(
        optimize_cnn,
        space,
        algo=tpe.suggest,
        trials=trials,
        max_evals=25,
    )

print("==================================")
print("Best Hyperparameters", best)

# You can retrain the final model with optimal hyperparameters on train+validation data

# Or you can use the model returned directly
# Find trial which has minimum loss value and use that model to perform evaluation on t
test_model = trials.results[np.argmin([r['loss'] for r in trials.results])]['model']

performance = test_model.evaluate(x_test, to_categorical(test_labels))

print("==================================")
print("Test Accuracy: ", performance[1])
```

```
Total Training Time is (s):
31.095835208892822
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.2429661912776022, 'optimizer': 'sgd'}
Accuracy:
0.337977152414294
----------------------------------------------------
Total Training Time is (s):
31.687371969223022
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.3226159513161642, 'optimizer': 'sgd'}
Accuracy:
0.3482864307689614
----------------------------------------------------
Total Training Time is (s):
28.15788960456848
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.1697117944569278, 'optimizer': 'Adam'}
Accuracy:
0.4446921147993595
----------------------------------------------------
Total Training Time is (s):
32.000370264053345
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.21779164306545729, 'optimizer': 'sgd'}
Accuracy:
0.3307327946586242
----------------------------------------------------
Total Training Time is (s):
32.85355305671692
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.10663941492259457, 'optimizer': 'sgd'}
Accuracy:
0.35135135135550327
----------------------------------------------------
Total Training Time is (s):
32.57329607009888
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.33037373096037836, 'optimizer': 'sgd'}
Accuracy:
0.3379771524433573
----------------------------------------------------
Total Training Time is (s):
32.80647110939026
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.1381682853825744, 'optimizer': 'sgd'}
Accuracy:
0.3296182780760382
----------------------------------------------------
Total Training Time is (s):
28.958810329437256
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.34275056286314465, 'optimizer': 'Adam'}
Accuracy:
0.4419058233823375
----------------------------------------------------
Total Training Time is (s):
32.93373417854309
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.3145589369201526, 'optimizer': 'sgd'}
Accuracy:
```

```
0.3207021454485654
----------------------------------------------------
Total Training Time is (s):
34.28903603553772
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.33845931234106297, 'optimizer': 'Adam'}
Accuracy:
0.5876288660125967
----------------------------------------------------
Total Training Time is (s):
27.753254175186157
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.2607511117740823, 'optimizer': 'sgd'}
Accuracy:
0.3296182780801901
----------------------------------------------------
Total Training Time is (s):
33.09608292579651
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.13697860925216643, 'optimizer': 'sgd'}
Accuracy:
0.34410699362474484
----------------------------------------------------
Total Training Time is (s):
32.954015254974365
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.10060224254979439, 'optimizer': 'sgd'}
Accuracy:
0.3402061855711622
----------------------------------------------------
Total Training Time is (s):
33.843745470047
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.19430122651964926, 'optimizer': 'Adam'}
Accuracy:
0.5984954026274177
----------------------------------------------------
Total Training Time is (s):
27.96817183494568
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.11444065209952078, 'optimizer': 'sgd'}
Accuracy:
0.3324045695262754
----------------------------------------------------
Total Training Time is (s):
33.4222207069397
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.10390735075834195, 'optimizer': 'sgd'}
Accuracy:
0.3482864307689614
----------------------------------------------------
Total Training Time is (s):
33.40985345840454
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.18057138820927132, 'optimizer': 'sgd'}
Accuracy:
0.32794650321253893
----------------------------------------------------
Total Training Time is (s):
33.81111192703247
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.2277213692352072, 'optimizer': 'Adam'}
```

```
Accuracy:
0.5976595151935922
----------------------------------------------------
Total Training Time is (s):
34.45823407173157
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.10651244975702923, 'optimizer': 'Adam'}
Accuracy:
0.5684034550346083
----------------------------------------------------
Total Training Time is (s):
34.07155179977417
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.29316343846787873, 'optimizer': 'Adam'}
Accuracy:
0.591529674037116
----------------------------------------------------
Total Training Time is (s):
34.26889753341675
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.20573788361981166, 'optimizer': 'Adam'}
Accuracy:
0.5739760379018675
----------------------------------------------------
Total Training Time is (s):
34.23374938964844
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.2738452663694213, 'optimizer': 'Adam'}
Accuracy:
0.5982167734828092
----------------------------------------------------
Total Training Time is (s):
34.337204694747925
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.27431157338690143, 'optimizer': 'Adam'}
Accuracy:
0.5851212036862085
----------------------------------------------------
Total Training Time is (s):
35.21518063545227
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.1917634352204038, 'optimizer': 'Adam'}
Accuracy:
0.5834494288185573
----------------------------------------------------
Total Training Time is (s):
35.195539474487305
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.29441982460016747, 'optimizer': 'Adam'}
Accuracy:
0.5639453886959606
----------------------------------------------------
100%|██████████| 25/25 [15:16<00:00, 36.66s/it, best loss: -0.5984954026274177]
==================================
Best Hyperparameters {'conv_kernel_size': 2, 'dropout_prob': 0.19430122651964926, 'op
3589/3589 [==============================] - 0s 123us/step
==================================
Test Accuracy:  0.5770409584925612
```

FEATURE Design

```
from skimage.feature import hog
from skimage import data, exposure

x_train = (train_image_array)
x_valid = (valid_image_array)
x_test = (test_image_array)

x_train = x_train.reshape((x_train.shape[0], 48, 48))
x_valid = x_valid.reshape((x_valid.shape[0], 48, 48))
x_test = x_test.reshape((x_test.shape[0], 48, 48))

hog_train = []
for i in range(len(x_train)):
  image = x_train[i]
  fd, hog_image = hog(image, orientations=8, pixels_per_cell=(16, 16),
                      cells_per_block=(1, 1), visualize=True, multichannel=False)
  hog_image_rescaled = exposure.rescale_intensity(hog_image, in_range=(0, 10))
  hog_train.append(hog_image_rescaled)

hog_valid = []
for i in range(len(x_valid)):
  image = x_valid[i]
  fd, hog_image = hog(image, orientations=8, pixels_per_cell=(16, 16),
                      cells_per_block=(1, 1), visualize=True, multichannel=False)
  hog_image_rescaled = exposure.rescale_intensity(hog_image, in_range=(0, 10))
  hog_valid.append(hog_image_rescaled)

hog_test = []
for i in range(len(x_test)):
  image = x_test[i]
  fd, hog_image = hog(image, orientations=8, pixels_per_cell=(16, 16),
                      cells_per_block=(1, 1), visualize=True, multichannel=False)
  hog_image_rescaled = exposure.rescale_intensity(hog_image, in_range=(0, 10))
  hog_test.append(hog_image_rescaled)

x_train = np.array(hog_train)
x_valid = np.array(hog_valid)
x_test = np.array(hog_test)

x_train = x_train.reshape((x_train.shape[0], 48, 48, 1))
x_valid = x_valid.reshape((x_valid.shape[0], 48, 48, 1))
x_test = x_test.reshape((x_test.shape[0], 48, 48, 1))
```

```

def optimize_cnn(hyperparameter):
```

```
 # Define model using hyperparameters
 cnn_model = Sequential([Conv2D(32, kernel_size=hyperparameter['conv_kernel_size'], ac
      Conv2D(32, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
      MaxPooling2D(pool_size=(2,2)), Dropout(hyperparameter['dropout_prob']),
      Conv2D(64, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
      Conv2D(64, kernel_size=hyperparameter['conv_kernel_size'], activation='relu
      MaxPooling2D(pool_size=(2,2)), Dropout(hyperparameter['dropout_prob']),
      Flatten(),
      Dense(512, activation='relu'),
      Dense(7, activation='softmax'),])

 cnn_model.compile(optimizer=hyperparameter['optimizer'], loss='categorical_crossentro
 time_callback = TimeHistory()
 hist = cnn_model.fit(x_train, to_categorical(train_labels), epochs=10, batch_size=256
 # print(hist.history.accuracy)
 print("Total Training Time is (s): ", sum(time_callback.times))
 # Evaluate accuracy on validation data
 performance = cnn_model.evaluate(x_valid, to_categorical(valid_labels), verbose=0)

 print("Hyperparameters: ", hyperparameter, "Accuracy: ", performance[1])
 print("-----------------------------------------------------")
 # We want to minimize loss i.e. negative of accuracy
 return({"status": STATUS_OK, "loss": -1*performance[1], "model":cnn_model})


# Define search space for hyper-parameters
space = {
  # The kernel_size for convolutions:
  'conv_kernel_size': hp.choice('conv_kernel_size', [1, 3, 5]),
  # Uniform distribution in finding appropriate dropout values
  'dropout_prob': hp.uniform('dropout_prob', 0.1, 0.35),
  # Choice of optimizer
  'optimizer': hp.choice('optimizer', ['Adam', 'sgd']),
}

trials = Trials()

# Find the best hyperparameters
best = fmin(
    optimize_cnn,
    space,
    algo=tpe.suggest,
    trials=trials,
    max_evals=25,
  )

print("==================================")
print("Best Hyperparameters", best)

# You can retrain the final model with optimal hyperparameters on train+validation data

# Or you can use the model returned directly
# Find trial which has minimum loss value and use that model to perform evaluation on t
test_model = trials.results[np.argmin([r['loss'] for r in trials.results])]['model']
```

```python

performance = test_model.evaluate(x_test, to_categorical(test_labels))

print("==================================")
print("Test Accuracy: ", performance[1])
```

```
Total Training Time is (s):
30.280741214752197
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.15049653462509077, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
----------------------------------------------------
Total Training Time is (s):
26.057782888412476
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.3327359916145542, 'optimizer': 'Adam'}
Accuracy:
0.24937308442878273
----------------------------------------------------
Total Training Time is (s):
25.993083477020264
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.2399034427313376, 'optimizer': 'Adam'}
Accuracy:
0.24937308442878273
----------------------------------------------------
Total Training Time is (s):
24.862027883529663
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.15711783288164408, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
----------------------------------------------------
Total Training Time is (s):
26.145740032196045
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.13095244695573482, 'optimizer': 'Adam'}
Accuracy:
0.24937308442878273
----------------------------------------------------
Total Training Time is (s):
21.854387521743774
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.3277228071731925, 'optimizer': 'Adam'}
Accuracy:
0.24937308442878273
----------------------------------------------------
Total Training Time is (s):
21.76009750366211
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.12063233345739746, 'optimizer': 'Adam'}
Accuracy:
0.24937308442878273
----------------------------------------------------
Total Training Time is (s):
26.186025619506836
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.1300360838648438, 'optimizer': 'Adam'}
Accuracy:
0.24937308442878273
----------------------------------------------------
Total Training Time is (s):
25.091683626174927
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.31162659374425034, 'optimizer': 'sgd'}
Accuracy:
```

```
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
26.44800066947937
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.32473622789596435, 'optimizer': 'Adam'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
25.53569984436035
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.25676837994360124, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
25.3596453666687
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.1996249235229065, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
26.942335844039917
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.2226626407591457, 'optimizer': 'Adam'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
25.856187105178833
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.2767054261515769, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
25.78175401687622
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.25144256564530276, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
21.05579113960266
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.1795332127981628, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
21.038676261901855
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.3163431451188834, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
26.15276527404785
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.19093288081246018, 'optimizer': 'sgd'}
```

```
{'conv_kernel_size': 5, 'dropout_prob': 0.19699288081240018, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
21.135244607925415
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.21503236289103644, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
26.280521392822266
Hyperparameters:
{'conv_kernel_size': 3, 'dropout_prob': 0.18627258090208043, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
26.11707830429077
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.15518590423516235, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
21.610968351364136
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.2137888917775868, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
26.30264401435852
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.1607458205645651, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
26.25912308692932
Hyperparameters:
{'conv_kernel_size': 5, 'dropout_prob': 0.10813003008178762, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
Total Training Time is (s):
21.570691347122192
Hyperparameters:
{'conv_kernel_size': 1, 'dropout_prob': 0.27555616085888457, 'optimizer': 'sgd'}
Accuracy:
0.24937308442878273
-----------------------------------------------------
100%|██████████| 25/25 [10:50<00:00, 26.00s/it, best loss: -0.24937308442878273]
==================================
Best Hyperparameters {'conv_kernel_size': 2, 'dropout_prob': 0.15049653462509077, 'op
3589/3589 [==============================] - 0s 87us/step
==================================
Test Accuracy:  0.2449150181191982
```