Homework3_CSCE633

November 12, 2021

1 Homework_3_432001358_CSCE_633_600

1.1 November 12, 2021

1.2 CSCE 633 600 (Machine Learning) Homework 3

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1.2.3 Question 1: Machine learning for facial emotion recognition

In this problem, we will process face images coming from the Facial Expression Recognition Challenge (presented in the International Conference of Machine Learning in 2013). The data is uploaded under Homework3 folder in the shared Google Drive. You are given three sets of data: training set (i.e., Q1 Train Data.csv), testing set (i.e., Q1 Test Data.csv), and validation set (i.e., Q1 Validation Data.csv). The data consists of 48X48 pixel grayscale images of faces. The faces have been automatically registered so that the face is more or less centered and occupies about the same amount of space in each image. The task is to categorize each face based on the emotion shown in the facial expression in seven categories. More information on the data can also be found in this link. All three files contain two columns: 1. The column labeled as "emotion" contains the emotion class with numeric code ranging from 0 to 6 (0=Angry, 1=Disgust, 2=Fear, 3=Happy, 4=Sad, 5=Surprise, 6=Neutral). 2. The column labeled as "pixels" contains the 2304 (i.e., 48 X 48) space-separated pixel values of the image in row-wise order, i.e., the first 48 numbers correspond to the first row of the image, the next 48 numbers to the second row of the image, etc.

[2]:
```
import numpy as np
import pandas as pd

import matplotlib.pyplot as plt
import tensorflow as tf


train_data = pd.read_csv('Q1_Train_Data.csv')
test_data = pd.read_csv('Q1_Test_Data.csv')
validation_data = pd.read_csv('Q1_Validation_Data.csv')

print (" ")
print("Shape of Train Data: {}".format(train_data.shape))
print (" ")
```

```
print("Shape of Test Data: {}".format(test_data.shape))
print (" ")
print("Shape of Validation Data: {}".format(validation_data.shape))
print (" ")
print(train_data.head)
```

```
Shape of Train Data: (28709, 2)

Shape of Test Data: (3589, 2)

Shape of Validation Data: (3589, 2)

<bound method NDFrame.head of        emotion
pixels
0            0  70 80 82 72 58 58 60 63 54 58 60 48 89 115 121…
1            0  151 150 147 155 148 133 111 140 170 174 182 15…
2            2  231 212 156 164 174 138 161 173 182 200 106 38…
3            4  24 32 36 30 32 23 19 20 30 41 21 22 32 34 21 1…
4            6  4 0 0 0 0 0 0 0 0 0 0 0 3 15 23 28 48 50 58 84…
…        …                                                …
28704        2  84 85 85 85 85 85 85 85 86 86 86 87 86 86 91 9…
28705        0  114 112 113 113 111 111 112 113 115 113 114 11…
28706        4  74 81 87 89 95 100 98 93 105 120 127 133 146 1…
28707        0  222 227 203 90 86 90 84 77 94 87 99 119 134 14…
28708        4  195 199 205 206 205 203 206 209 208 210 212 21…

[28709 rows x 2 columns]>
```

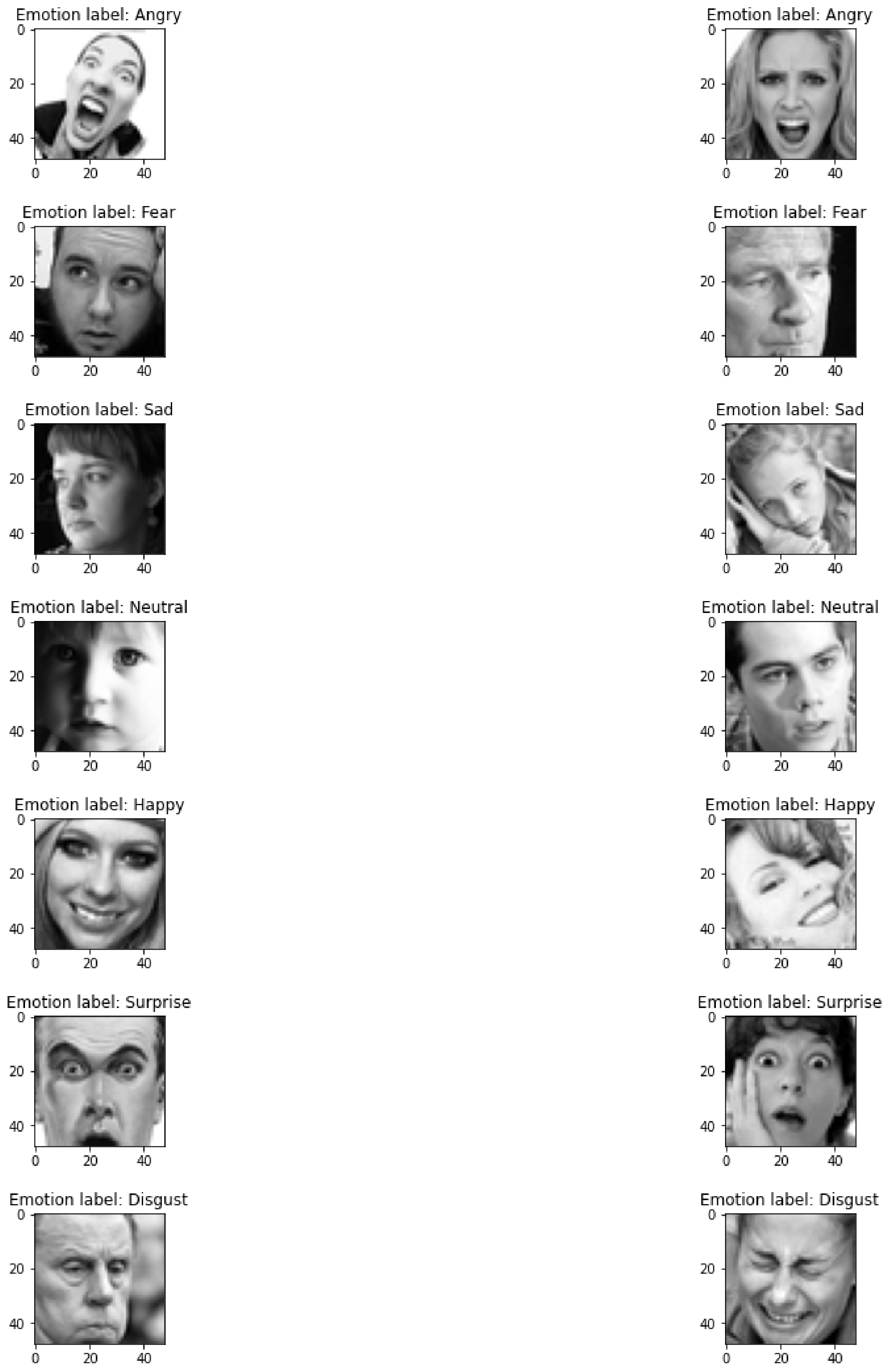
1.2.4 (a) (1 points) Visualization: Randomly select and visualize 1-2 images per emotion. Note: You can find a useful link on image pre-processing here: https://www.tensorflow.org/api_docs/python/tf/image/per_image_standardization

```
[3]: def string_to_int(st):
       ar= list((int(x)/255 - 0.5)  for x in st.split(' '))
       return ar

     def get_pixels_int(df):
       df['pixels_int']=df.apply(lambda st: np.
      ↪array(string_to_int(st['pixels'])),axis=1)

     get_pixels_int(train_data)
     get_pixels_int(test_data)
     get_pixels_int(validation_data)



     print(train_data.head)
```

```
<bound method NDFrame.head of        emotion  …
pixels_int
0            0  …  [-0.22549019607843135, -0.18627450980392157, -…
1            0  …  [0.09215686274509804, 0.08823529411764708, 0.0…
2            2  …  [0.40588235294117647, 0.3313725490196079, 0.11…
3            4  …  [-0.40588235294117647, -0.37450980392156863, -…
4            6  …  [-0.4843137254901961, -0.5, -0.5, -0.5, -0.5, …
…         …  …                                                …
28704        2  …  [-0.17058823529411765, -0.16666666666666669, -…
28705        0  …  [-0.052941176470588214, -0.0607843137254902, -…
28706        4  …  [-0.20980392156862743, -0.1823529411764706, -0…
28707        0  …  [0.37058823529411766, 0.3901960784313725, 0.29…
28708        4  …  [0.2647058823529411, 0.2803921568627451, 0.303…

[28709 rows x 3 columns]>
```

[7]:
```
# plt.rcParams["figure.figsize"] = (2,300)

plt.figure(figsize=(400,400))

emotion_category={0:'Angry', 1:'Disgust', 2:'Fear', 3:'Happy', 4:'Sad', 5:
↪'Surprise', 6:'Neutral'}

emotions= train_data['emotion'].unique().tolist()

fig, ax=plt.subplots(len(emotions),2,figsize=(15,15))
fig.tight_layout(pad=3.0)
# print (emotions)
plot_num=0
for emotion in emotions:
  imgs=train_data[train_data["emotion"]==emotion]
  samples=imgs.sample(n=2)
  for i in range(samples.shape[0]):
    img=samples.iloc[i]
    ax[int(plot_num/2),plot_num%2].set_title("Emotion label: {}".
↪format(emotion_category[emotion]))
    ax[int(plot_num/2),plot_num%2].imshow(np.array(img['pixels_int']).
↪reshape(48,48),cmap=plt.get_cmap('gray'))
    plot_num+=1
```

```
<Figure size 28800x28800 with 0 Axes>
```


Emotion label: Angry
Emotion label: Angry
Emotion label: Fear
Emotion label: Fear
Emotion label: Sad
Emotion label: Sad
Emotion label: Neutral
Emotion label: Neutral
Emotion label: Happy
Emotion label: Happy
Emotion label: Surprise
Emotion label: Surprise
Emotion label: Disgust
Emotion label: Disgust

1.2.5 (b) (1 points) Data exploration: Count the number of samples per emotion in the training data.

[8]:
```
samples_count=train_data.groupby(['emotion']).count()
samples_count=samples_count[['pixels']].rename({'pixels': 'size'}, axis=1)
samples_count
```

[8]:
```
         size
emotion
0        3995
1         436
2        4097
3        7215
4        4830
5        3171
6        4965
```

1.2.6 (c) (4 points) Image classification with FNNs: In this part, you will use a feed-forward neural network (FNN) (also called multilayer perceptron") to perform the emotion classification task. The input of the FNN comprises of all the pixels of the image.

[9]:
```
from tensorflow.keras.models import Sequential
from tensorflow.keras.layers import Dense, Dropout
from tensorflow.keras.utils import to_categorical
from tensorflow.keras import regularizers

train_emotions=np.array(list(train_data['emotion']))
train_pixels=np.array(list(train_data['pixels_int']))


import time

class TimeHistory(tf.keras.callbacks.Callback):
    def on_train_begin(self, logs={}):
        self.times = []
        self.epoch_time_start = time.time()
    # def on_epoch_begin(self, epoch, logs={}):
    #     self.epoch_time_start = time.time()

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

```
model1 = Sequential([
  Dense(784*2, activation='relu', input_shape=(48*48,),␣
 ↪name="first_hidden_layer"),
  Dense(784, activation='relu', name="second_hidden_layer"),
  Dense(784//2, activation='relu', name="third_hidden_layer"),
  Dense(784//4, activation='relu', name="fourth_hidden_layer"),
  Dense(len(emotions), activation='softmax'),
])

model2 = Sequential([
  Dense(784*2, activation='elu', input_shape=(48*48,),␣
 ↪name="first_hidden_layer"),
  Dense(784, activation='elu', name="second_hidden_layer"),
  Dense(784//2, activation='elu', name="third_hidden_layer"),
  Dropout(0.25),
  Dense(len(emotions), activation='softmax'),
])


model3 = Sequential([
  Dense(2000, activation='elu', input_shape=(48*48,),␣
 ↪name="first_hidden_layer"),
  Dense(1000, activation='elu', name="second_hidden_layer"),
  Dense(500, activation='elu', name="third_hidden_layer"),
  Dropout(0.25),
  Dense(len(emotions), activation='softmax'),
])


model4 = Sequential([
  Dense(2000, activation='elu', input_shape=(48*48,),␣
 ↪name="first_hidden_layer"),
  Dense(1000, activation='elu', name="second_hidden_layer"),
  Dense(500, activation='elu', name="third_hidden_layer"),
  Dense(250, activation='elu', name="fourth_hidden_layer"),
  Dense(784, activation='relu', name="fifth_hidden_layer"),
  Dropout(0.25),
  Dense(len(emotions), activation='softmax'),
])


model5 = Sequential([
  Dense(2000, activation='elu', input_shape=(48*48,),␣
 ↪name="first_hidden_layer", kernel_regularizer=regularizers.l2(0.0001)),
  Dense(1000, activation='elu', name="second_hidden_layer",␣
 ↪kernel_regularizer=regularizers.l2(0.0001)),
  Dense(500, activation='elu', name="third_hidden_layer",␣
 ↪kernel_regularizer=regularizers.l2(0.0001)),
  Dense(250, activation='elu', name="fourth_hidden_layer",␣
 ↪kernel_regularizer=regularizers.l2(0.0001)),
  Dropout(0.25),
  Dense(len(emotions), activation='softmax'),
])
```

[10]:
```
time_callback = TimeHistory()

model1.compile(optimizer='adam',␣
 ↪loss='categorical_crossentropy',metrics=['accuracy'])
model2.compile(optimizer='adam',␣
 ↪loss='categorical_crossentropy',metrics=['accuracy'])
model3.compile(optimizer='adam',␣
 ↪loss='categorical_crossentropy',metrics=['accuracy'])
model4.compile(optimizer='adam',␣
 ↪loss='categorical_crossentropy',metrics=['accuracy'])
model5.compile(optimizer='adam',␣
 ↪loss='categorical_crossentropy',metrics=['accuracy'])



print("Train image shape: ", train_pixels.shape)
print(train_emotions.shape)

time_to_train=[]
flatten_train_images = train_pixels

history1=model1.fit(np.array(flatten_train_images),␣
 ↪to_categorical(train_emotions), epochs=20, batch_size=256,callbacks =␣
 ↪[time_callback])
time_to_train.append(time_callback.times)


history2=model2.fit(np.array(flatten_train_images),␣
 ↪to_categorical(train_emotions), epochs=20, batch_size=256,callbacks =␣
 ↪[time_callback])
time_to_train.append(time_callback.times)
history3=model3.fit(np.array(flatten_train_images),␣
 ↪to_categorical(train_emotions), epochs=20, batch_size=256,callbacks =␣
 ↪[time_callback])
time_to_train.append(time_callback.times)
history4=model4.fit(np.array(flatten_train_images),␣
 ↪to_categorical(train_emotions), epochs=20, batch_size=256,callbacks =␣
 ↪[time_callback])
```

```
time_to_train.append(time_callback.times)
history5=model5.fit(np.array(flatten_train_images),␣
 ↪to_categorical(train_emotions), epochs=20, batch_size=256,callbacks =␣
 ↪[time_callback])
time_to_train.append(time_callback.times)
```

```
Train image shape:  (28709, 2304)
(28709,)
Epoch 1/20
113/113 [==============================] - 4s 11ms/step - loss: 1.6840 -
accuracy: 0.3310
Epoch 2/20
113/113 [==============================] - 1s 11ms/step - loss: 1.5542 -
accuracy: 0.3973
Epoch 3/20
113/113 [==============================] - 1s 10ms/step - loss: 1.4730 -
accuracy: 0.4306
Epoch 4/20
113/113 [==============================] - 1s 10ms/step - loss: 1.4030 -
accuracy: 0.4601
Epoch 5/20
113/113 [==============================] - 1s 10ms/step - loss: 1.3249 -
accuracy: 0.4910
Epoch 6/20
113/113 [==============================] - 1s 10ms/step - loss: 1.2336 -
accuracy: 0.5309
Epoch 7/20
113/113 [==============================] - 1s 10ms/step - loss: 1.1446 -
accuracy: 0.5661
Epoch 8/20
113/113 [==============================] - 1s 10ms/step - loss: 1.0407 -
accuracy: 0.6076
Epoch 9/20
113/113 [==============================] - 1s 10ms/step - loss: 0.9452 -
accuracy: 0.6470
Epoch 10/20
113/113 [==============================] - 1s 10ms/step - loss: 0.8322 -
accuracy: 0.6881
Epoch 11/20
113/113 [==============================] - 1s 10ms/step - loss: 0.7347 -
accuracy: 0.7276
Epoch 12/20
113/113 [==============================] - 1s 10ms/step - loss: 0.6557 -
accuracy: 0.7582
Epoch 13/20
113/113 [==============================] - 1s 10ms/step - loss: 0.5660 -
accuracy: 0.7953
Epoch 14/20
```

```
113/113 [==============================] - 1s 10ms/step - loss: 0.4861 -
accuracy: 0.8202
Epoch 15/20
113/113 [==============================] - 1s 10ms/step - loss: 0.4244 -
accuracy: 0.8468
Epoch 16/20
113/113 [==============================] - 1s 11ms/step - loss: 0.3649 -
accuracy: 0.8711
Epoch 17/20
113/113 [==============================] - 1s 10ms/step - loss: 0.3311 -
accuracy: 0.8817
Epoch 18/20
113/113 [==============================] - 1s 10ms/step - loss: 0.2946 -
accuracy: 0.8944
Epoch 19/20
113/113 [==============================] - 1s 11ms/step - loss: 0.2479 -
accuracy: 0.9122
Epoch 20/20
113/113 [==============================] - 1s 11ms/step - loss: 0.2313 -
accuracy: 0.9204
Epoch 1/20
113/113 [==============================] - 2s 10ms/step - loss: 1.9349 -
accuracy: 0.2956
Epoch 2/20
113/113 [==============================] - 1s 10ms/step - loss: 1.7017 -
accuracy: 0.3464
Epoch 3/20
113/113 [==============================] - 1s 10ms/step - loss: 1.6120 -
accuracy: 0.3824
Epoch 4/20
113/113 [==============================] - 1s 11ms/step - loss: 1.5344 -
accuracy: 0.4082
Epoch 5/20
113/113 [==============================] - 1s 10ms/step - loss: 1.4647 -
accuracy: 0.4392
Epoch 6/20
113/113 [==============================] - 1s 11ms/step - loss: 1.4076 -
accuracy: 0.4607
Epoch 7/20
113/113 [==============================] - 1s 10ms/step - loss: 1.3538 -
accuracy: 0.4807
Epoch 8/20
113/113 [==============================] - 1s 11ms/step - loss: 1.2961 -
accuracy: 0.5060
Epoch 9/20
113/113 [==============================] - 1s 10ms/step - loss: 1.2475 -
accuracy: 0.5244
Epoch 10/20
```

```
113/113 [==============================] - 1s 10ms/step - loss: 1.1840 -
accuracy: 0.5502
Epoch 11/20
113/113 [==============================] - 1s 11ms/step - loss: 1.1234 -
accuracy: 0.5747
Epoch 12/20
113/113 [==============================] - 1s 10ms/step - loss: 1.0667 -
accuracy: 0.5981
Epoch 13/20
113/113 [==============================] - 1s 10ms/step - loss: 0.9900 -
accuracy: 0.6283
Epoch 14/20
113/113 [==============================] - 1s 10ms/step - loss: 0.9311 -
accuracy: 0.6522
Epoch 15/20
113/113 [==============================] - 1s 11ms/step - loss: 0.8564 -
accuracy: 0.6791
Epoch 16/20
113/113 [==============================] - 1s 11ms/step - loss: 0.8003 -
accuracy: 0.7007
Epoch 17/20
113/113 [==============================] - 1s 11ms/step - loss: 0.7307 -
accuracy: 0.7295
Epoch 18/20
113/113 [==============================] - 1s 11ms/step - loss: 0.6490 -
accuracy: 0.7594
Epoch 19/20
113/113 [==============================] - 1s 11ms/step - loss: 0.5808 -
accuracy: 0.7840
Epoch 20/20
113/113 [==============================] - 1s 11ms/step - loss: 0.5216 -
accuracy: 0.8090
Epoch 1/20
113/113 [==============================] - 2s 12ms/step - loss: 1.9894 -
accuracy: 0.2895
Epoch 2/20
113/113 [==============================] - 1s 12ms/step - loss: 1.7133 -
accuracy: 0.3453
Epoch 3/20
113/113 [==============================] - 1s 12ms/step - loss: 1.6252 -
accuracy: 0.3750
Epoch 4/20
113/113 [==============================] - 1s 11ms/step - loss: 1.5295 -
accuracy: 0.4118
Epoch 5/20
113/113 [==============================] - 1s 11ms/step - loss: 1.4681 -
accuracy: 0.4380
Epoch 6/20
```

```
113/113 [==============================] - 1s 12ms/step - loss: 1.3928 -
accuracy: 0.4678
Epoch 7/20
113/113 [==============================] - 1s 12ms/step - loss: 1.3372 -
accuracy: 0.4922
Epoch 8/20
113/113 [==============================] - 1s 11ms/step - loss: 1.2934 -
accuracy: 0.5095
Epoch 9/20
113/113 [==============================] - 1s 11ms/step - loss: 1.2291 -
accuracy: 0.5343
Epoch 10/20
113/113 [==============================] - 1s 11ms/step - loss: 1.1772 -
accuracy: 0.5555
Epoch 11/20
113/113 [==============================] - 1s 11ms/step - loss: 1.1051 -
accuracy: 0.5798
Epoch 12/20
113/113 [==============================] - 1s 11ms/step - loss: 1.0331 -
accuracy: 0.6125
Epoch 13/20
113/113 [==============================] - 1s 11ms/step - loss: 0.9570 -
accuracy: 0.6419
Epoch 14/20
113/113 [==============================] - 1s 12ms/step - loss: 0.9059 -
accuracy: 0.6613
Epoch 15/20
113/113 [==============================] - 1s 12ms/step - loss: 0.8175 -
accuracy: 0.6986
Epoch 16/20
113/113 [==============================] - 1s 12ms/step - loss: 0.7428 -
accuracy: 0.7217
Epoch 17/20
113/113 [==============================] - 1s 12ms/step - loss: 0.6854 -
accuracy: 0.7454
Epoch 18/20
113/113 [==============================] - 1s 12ms/step - loss: 0.6183 -
accuracy: 0.7738
Epoch 19/20
113/113 [==============================] - 1s 12ms/step - loss: 0.5543 -
accuracy: 0.7951
Epoch 20/20
113/113 [==============================] - 1s 11ms/step - loss: 0.4955 -
accuracy: 0.8173
Epoch 1/20
113/113 [==============================] - 3s 14ms/step - loss: 1.7657 -
accuracy: 0.3023
Epoch 2/20
```

```
113/113 [==============================] - 1s 13ms/step - loss: 1.6109 -
accuracy: 0.3669
Epoch 3/20
113/113 [==============================] - 1s 12ms/step - loss: 1.5468 -
accuracy: 0.3968
Epoch 4/20
113/113 [==============================] - 1s 12ms/step - loss: 1.4955 -
accuracy: 0.4160
Epoch 5/20
113/113 [==============================] - 1s 12ms/step - loss: 1.4519 -
accuracy: 0.4345
Epoch 6/20
113/113 [==============================] - 1s 12ms/step - loss: 1.4028 -
accuracy: 0.4595
Epoch 7/20
113/113 [==============================] - 1s 12ms/step - loss: 1.3504 -
accuracy: 0.4803
Epoch 8/20
113/113 [==============================] - 1s 12ms/step - loss: 1.2974 -
accuracy: 0.4972
Epoch 9/20
113/113 [==============================] - 1s 12ms/step - loss: 1.2347 -
accuracy: 0.5253
Epoch 10/20
113/113 [==============================] - 1s 12ms/step - loss: 1.1801 -
accuracy: 0.5493
Epoch 11/20
113/113 [==============================] - 1s 12ms/step - loss: 1.1094 -
accuracy: 0.5798
Epoch 12/20
113/113 [==============================] - 1s 12ms/step - loss: 1.0416 -
accuracy: 0.6036
Epoch 13/20
113/113 [==============================] - 1s 12ms/step - loss: 0.9708 -
accuracy: 0.6318
Epoch 14/20
113/113 [==============================] - 1s 12ms/step - loss: 0.8874 -
accuracy: 0.6667
Epoch 15/20
113/113 [==============================] - 1s 12ms/step - loss: 0.8051 -
accuracy: 0.6959
Epoch 16/20
113/113 [==============================] - 1s 12ms/step - loss: 0.7204 -
accuracy: 0.7306
Epoch 17/20
113/113 [==============================] - 1s 12ms/step - loss: 0.6525 -
accuracy: 0.7576
Epoch 18/20
```

```
113/113 [==============================] - 1s 12ms/step - loss: 0.5795 -
accuracy: 0.7865
Epoch 19/20
113/113 [==============================] - 1s 12ms/step - loss: 0.5101 -
accuracy: 0.8129
Epoch 20/20
113/113 [==============================] - 1s 12ms/step - loss: 0.4550 -
accuracy: 0.8345
Epoch 1/20
113/113 [==============================] - 2s 14ms/step - loss: 2.3903 -
accuracy: 0.2903
Epoch 2/20
113/113 [==============================] - 2s 14ms/step - loss: 2.0942 -
accuracy: 0.3465
Epoch 3/20
113/113 [==============================] - 2s 14ms/step - loss: 1.9958 -
accuracy: 0.3712
Epoch 4/20
113/113 [==============================] - 2s 14ms/step - loss: 1.9026 -
accuracy: 0.3957
Epoch 5/20
113/113 [==============================] - 2s 14ms/step - loss: 1.8173 -
accuracy: 0.4180
Epoch 6/20
113/113 [==============================] - 2s 14ms/step - loss: 1.7519 -
accuracy: 0.4341
Epoch 7/20
113/113 [==============================] - 2s 14ms/step - loss: 1.7040 -
accuracy: 0.4471
Epoch 8/20
113/113 [==============================] - 2s 14ms/step - loss: 1.6497 -
accuracy: 0.4661
Epoch 9/20
113/113 [==============================] - 2s 14ms/step - loss: 1.6144 -
accuracy: 0.4777
Epoch 10/20
113/113 [==============================] - 2s 14ms/step - loss: 1.5756 -
accuracy: 0.4917
Epoch 11/20
113/113 [==============================] - 2s 14ms/step - loss: 1.5463 -
accuracy: 0.5017
Epoch 12/20
113/113 [==============================] - 2s 14ms/step - loss: 1.5239 -
accuracy: 0.5153
Epoch 13/20
113/113 [==============================] - 2s 15ms/step - loss: 1.4955 -
accuracy: 0.5262
Epoch 14/20
```

```
113/113 [==============================] - 2s 14ms/step - loss: 1.4805 -
accuracy: 0.5371
Epoch 15/20
113/113 [==============================] - 2s 14ms/step - loss: 1.4442 -
accuracy: 0.5529
Epoch 16/20
113/113 [==============================] - 2s 14ms/step - loss: 1.4307 -
accuracy: 0.5584
Epoch 17/20
113/113 [==============================] - 2s 14ms/step - loss: 1.4015 -
accuracy: 0.5806
Epoch 18/20
113/113 [==============================] - 2s 14ms/step - loss: 1.3664 -
accuracy: 0.5989
Epoch 19/20
113/113 [==============================] - 2s 14ms/step - loss: 1.3507 -
accuracy: 0.6087
Epoch 20/20
113/113 [==============================] - 2s 14ms/step - loss: 1.3278 -
accuracy: 0.6270
```

1.2.7 (c.i) (3 points) Experiment on the validation set with different FNN hyper-parameters, e.g.layers, nodes per layer, activation function, dropout, weight regularization, etc. For each hyper-parameter combination that you have used, please report the following: (1) emotion classification accuracy on the training and validation sets; (2) running time for training the FNN; (3) parameters for each FNN. For 2-3 hyper-parameter combinations, please also plot the cross-entropy loss over the number of iterations during training. Note: If running the FNN takes a long time, you can subsample the input images to a smaller size (e.g., 24 x 24).

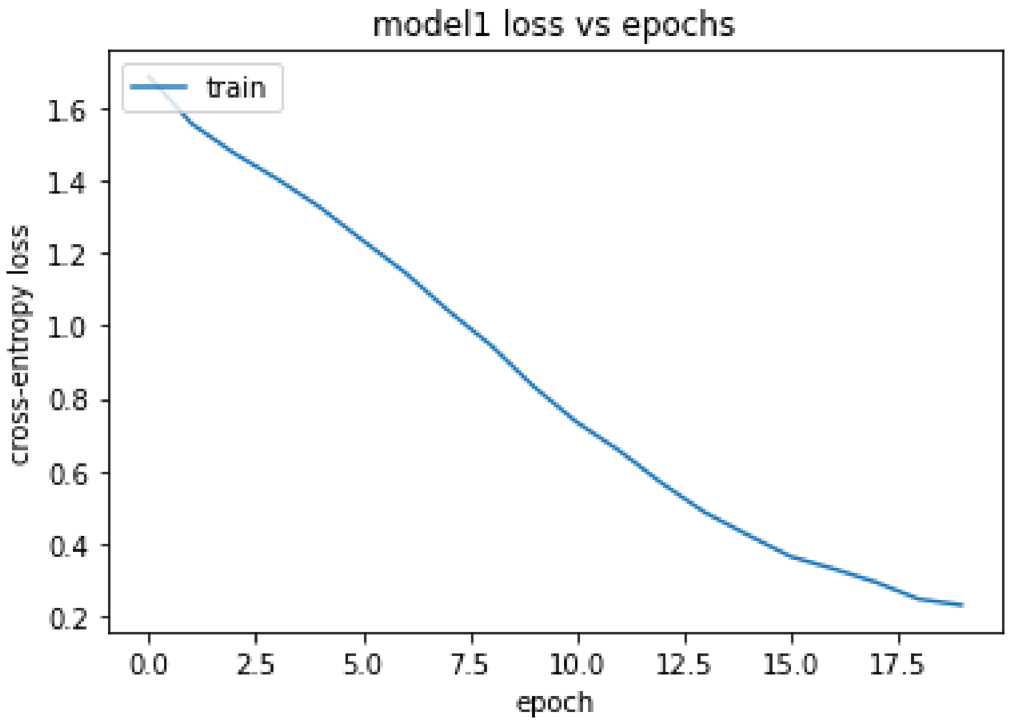
[11]:
```python
# print (time_to_train)
# for i in time_to_train:
#   print (sum(i))

validation_emotions=np.array(list(validation_data['emotion']))
validation_pixels=np.array(list(validation_data['pixels_int']))

flatten_validation_images = validation_pixels
validation_performances=[]
models=[model1,model2,model3,model4,model5]
model_names=['model1','model2','model3','model4','model5']
histories=[history1,history2,history3,history4,history5]
for i in range(len(models)):
  print (" ")
  print ("Required details for {}".format(model_names[i]))
  print (" ")
```

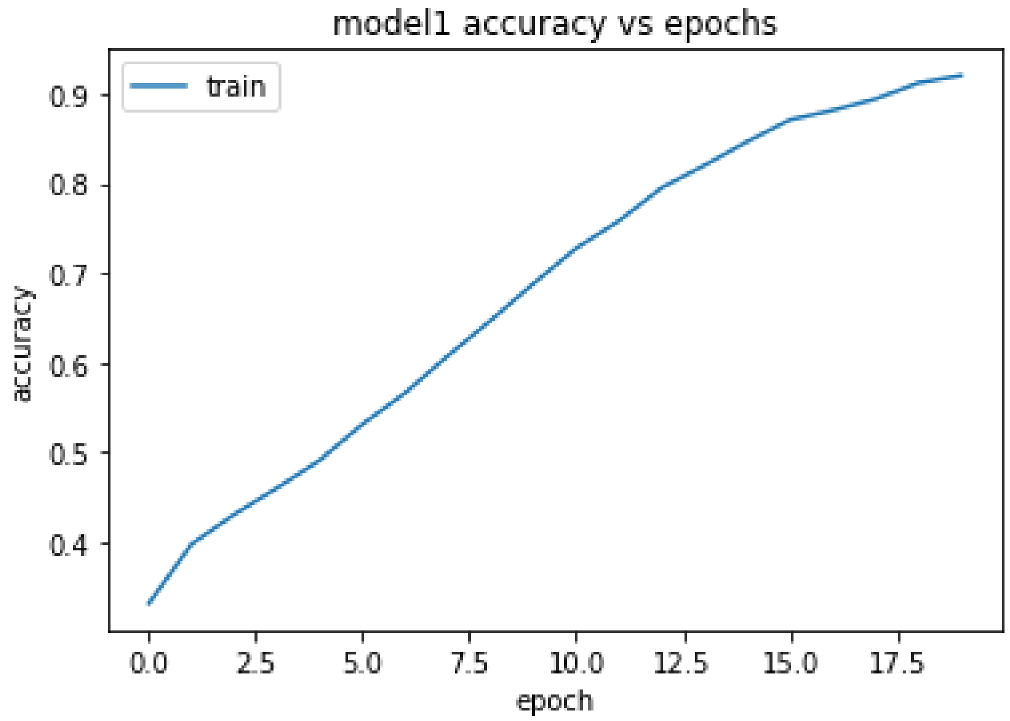
```
 performance1 = models[i].evaluate(flatten_train_images,␣
↪to_categorical(train_emotions))
 print("Emotion Classification Accuracy on the Training set: {0}".
↪format(performance1[1]))
 print (" ")
 performance2 = models[i].evaluate(flatten_validation_images,␣
↪to_categorical(validation_emotions))
 validation_performances.append(performance2[1])
 print("Emotion Classification Accuracy on the Validation set: {0}".
↪format(performance2[1]))
 print (" ")
 print ("Running time for training the FNN: {} ms".
↪format(str(time_to_train[i][0])))
 print (" ")
 print ("Parameters for the model:")
 print (" ")
 print (models[i].get_config())
 print (" ")
 print (models[i].summary())


 print (" ")
 print('Number of Epochs used to train the model: ', len(histories[i].
↪history['loss']))




 print(" ")
 # print(history.history.keys())
 # summarize history for loss
 plt.plot(histories[i].history['loss'])
 plt.title('{} loss vs epochs'.format(model_names[i]))
 plt.ylabel('cross-entropy loss')
 plt.xlabel('epoch')
 plt.legend(['train'], loc='upper left')
 plt.show()
 # summarize history for accuracy
 plt.plot(histories[i].history['accuracy'])
 plt.title('{} accuracy vs epochs'.format(model_names[i]))
 plt.ylabel('accuracy')
 plt.xlabel('epoch')
 plt.legend(['train'], loc='upper left')
 plt.show()

 print (" ")
 print (" ")
```

```
# performance = model1.evaluate(flatten_test_images,␣
↪to_categorical(validation_emotions))
# print("Accuracy on Test samples: {0}".format(performance[1]))
# performance = model2.evaluate(flatten_test_images,␣
↪to_categorical(validation_emotions))
# print("Accuracy on Test samples: {0}".format(performance[1]))
# performance = model3.evaluate(flatten_test_images,␣
↪to_categorical(validation_emotions))
# print("Accuracy on Test samples: {0}".format(performance[1]))
# performance = model4.evaluate(flatten_test_images,␣
↪to_categorical(validation_emotions))
# print("Accuracy on Test samples: {0}".format(performance[1]))
# performance = model5.evaluate(flatten_test_images,␣
↪to_categorical(validation_emotions))
# print("Accuracy on Test samples: {0}".format(performance[1]))
```

```
Required details for model1

898/898 [==============================] - 4s 4ms/step - loss: 0.1703 -
accuracy: 0.9428
Emotion Classification Accuracy on the Training set: 0.9428402185440063

113/113 [==============================] - 1s 4ms/step - loss: 3.3851 -
accuracy: 0.4734
Emotion Classification Accuracy on the Validation set: 0.4733909070491791

Running time for training the FNN: 26.956640243530273 ms

Parameters for the model:

{'name': 'sequential', 'layers': [{'class_name': 'InputLayer', 'config':
{'batch_input_shape': (None, 2304), 'dtype': 'float32', 'sparse': False,
'ragged': False, 'name': 'first_hidden_layer_input'}}, {'class_name': 'Dense',
'config': {'name': 'first_hidden_layer', 'trainable': True, 'batch_input_shape':
(None, 2304), 'dtype': 'float32', 'units': 1568, 'activation': 'relu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dense', 'config': {'name': 'second_hidden_layer',
'trainable': True, 'dtype': 'float32', 'units': 784, 'activation': 'relu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
```

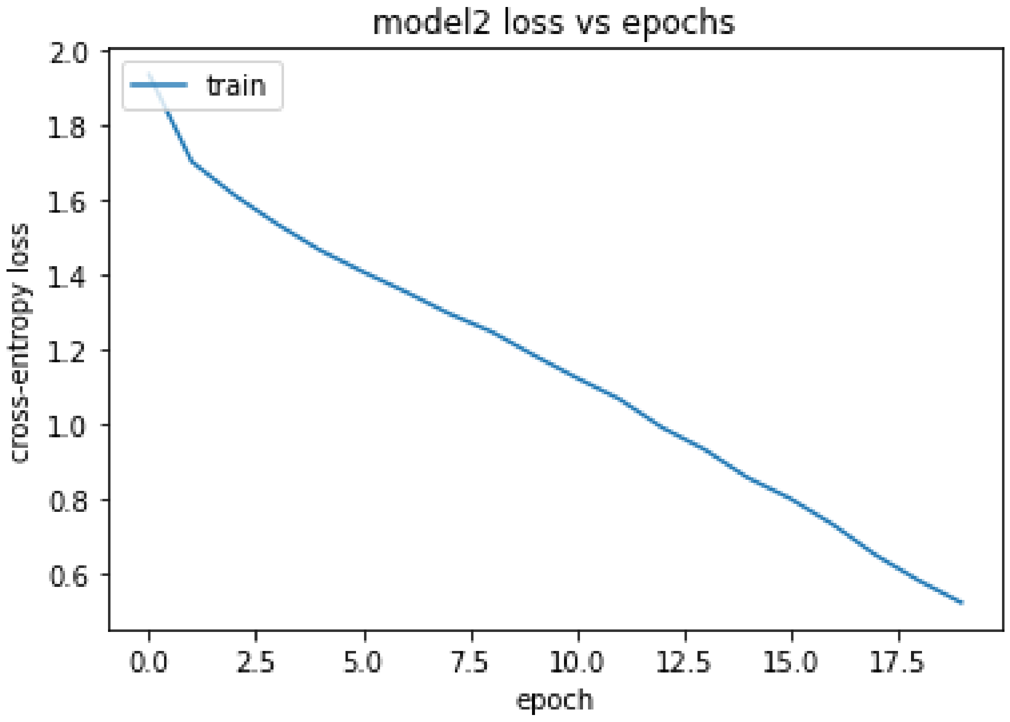
```
None}}, {'class_name': 'Dense', 'config': {'name': 'third_hidden_layer',
'trainable': True, 'dtype': 'float32', 'units': 392, 'activation': 'relu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dense', 'config': {'name': 'fourth_hidden_layer',
'trainable': True, 'dtype': 'float32', 'units': 196, 'activation': 'relu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dense', 'config': {'name': 'dense', 'trainable': True,
'dtype': 'float32', 'units': 7, 'activation': 'softmax', 'use_bias': True,
'kernel_initializer': {'class_name': 'GlorotUniform', 'config': {'seed': None}},
'bias_initializer': {'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer':
None, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}]}

Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 first_hidden_layer (Dense)  (None, 1568)              3614240

 second_hidden_layer (Dense)  (None, 784)              1230096

 third_hidden_layer (Dense)  (None, 392)               307720

 fourth_hidden_layer (Dense)  (None, 196)              77028

 dense (Dense)               (None, 7)                 1379

=================================================================
Total params: 5,230,463
Trainable params: 5,230,463
Non-trainable params: 0
_________________________________________________________________
None

Number of Epochs used to train the model:  20
```

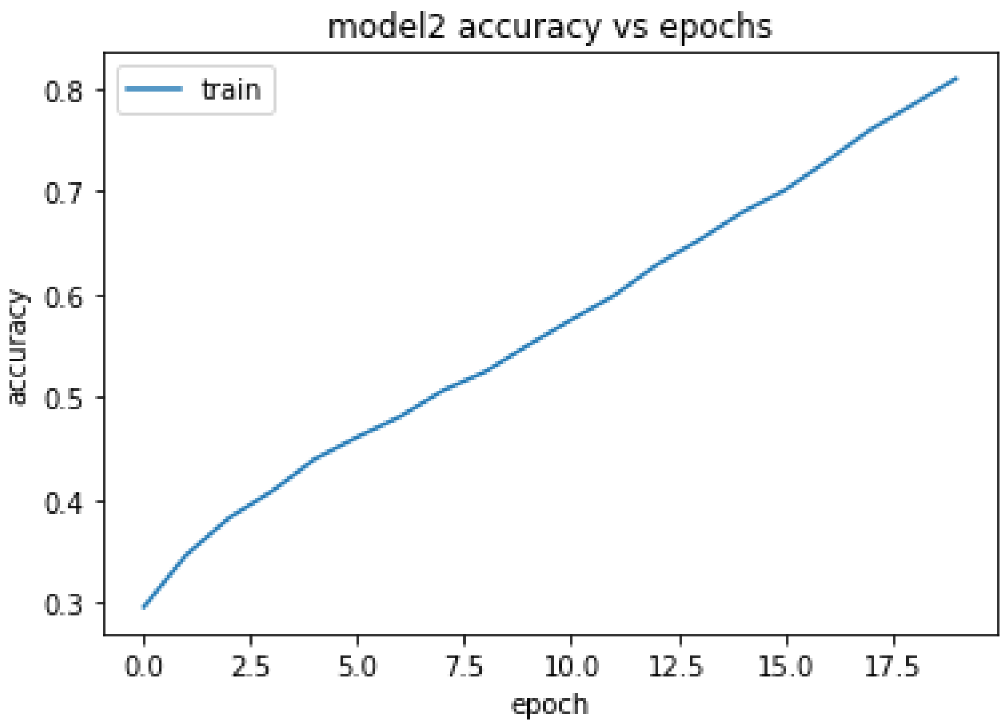

model1 loss vs epochs
train
cross-entropy loss
epoch
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5


model1 accuracy vs epochs
train
accuracy
epoch
0.4
0.5
0.6
0.7
0.8
0.9
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5

```
Required details for model2

898/898 [==============================] - 4s 5ms/step - loss: 0.3391 -
accuracy: 0.8836
Emotion Classification Accuracy on the Training set: 0.8835556507110596

113/113 [==============================] - 1s 5ms/step - loss: 2.2094 -
accuracy: 0.4544
Emotion Classification Accuracy on the Validation set: 0.45444414019584656

Running time for training the FNN: 24.502355337142944 ms

Parameters for the model:

{'name': 'sequential_1', 'layers': [{'class_name': 'InputLayer', 'config':
{'batch_input_shape': (None, 2304), 'dtype': 'float32', 'sparse': False,
'ragged': False, 'name': 'first_hidden_layer_input'}}, {'class_name': 'Dense',
'config': {'name': 'first_hidden_layer', 'trainable': True, 'batch_input_shape':
(None, 2304), 'dtype': 'float32', 'units': 1568, 'activation': 'elu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dense', 'config': {'name': 'second_hidden_layer',
'trainable': True, 'dtype': 'float32', 'units': 784, 'activation': 'elu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dense', 'config': {'name': 'third_hidden_layer',
'trainable': True, 'dtype': 'float32', 'units': 392, 'activation': 'elu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dropout', 'config': {'name': 'dropout', 'trainable':
True, 'dtype': 'float32', 'rate': 0.25, 'noise_shape': None, 'seed': None}},
{'class_name': 'Dense', 'config': {'name': 'dense_1', 'trainable': True,
'dtype': 'float32', 'units': 7, 'activation': 'softmax', 'use_bias': True,
'kernel_initializer': {'class_name': 'GlorotUniform', 'config': {'seed': None}},
'bias_initializer': {'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer':
None, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}]}

Model: "sequential_1"
```

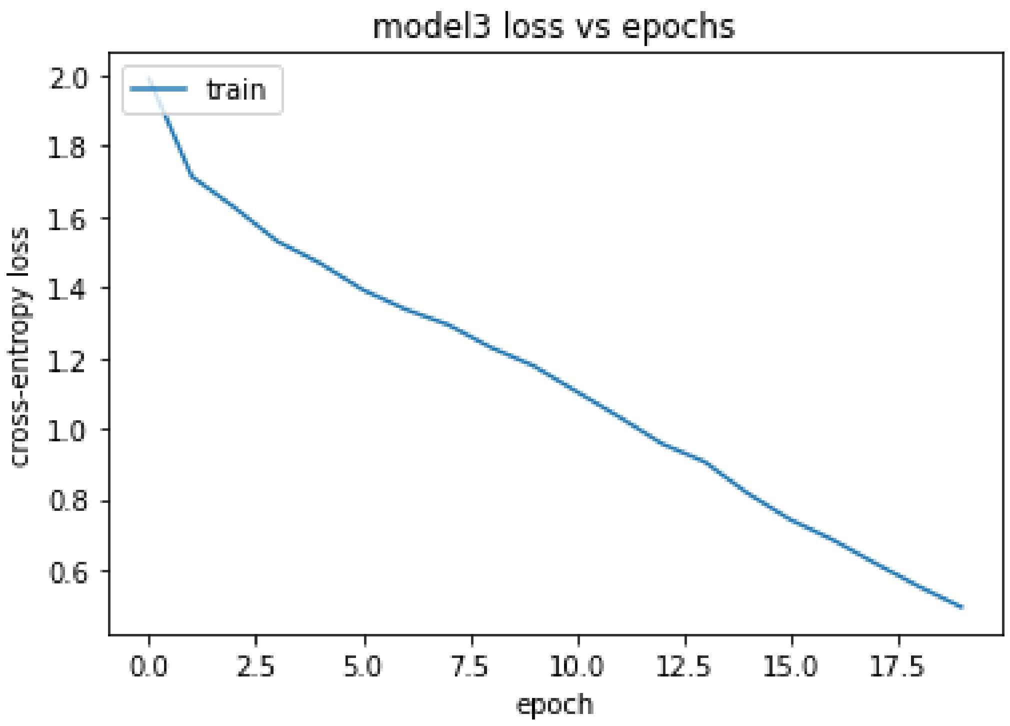
```
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 first_hidden_layer (Dense)  (None, 1568)              3614240

 second_hidden_layer (Dense)  (None, 784)              1230096

 third_hidden_layer (Dense)  (None, 392)               307720

 dropout (Dropout)           (None, 392)               0

 dense_1 (Dense)             (None, 7)                 2751

=================================================================
Total params: 5,154,807
Trainable params: 5,154,807
Non-trainable params: 0
_________________________________________________________________
None

Number of Epochs used to train the model:  20
```

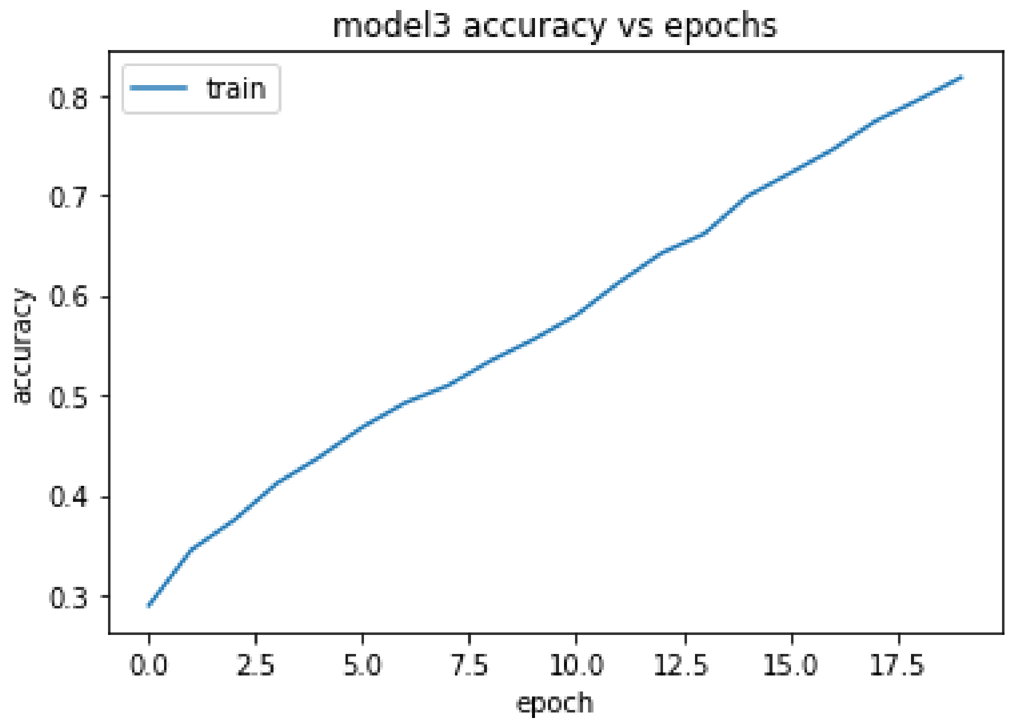




```
Required details for model3

898/898 [==============================] - 4s 5ms/step - loss: 0.2900 -
accuracy: 0.9070
Emotion Classification Accuracy on the Training set: 0.9069629907608032

113/113 [==============================] - 1s 5ms/step - loss: 2.2753 -
accuracy: 0.4695
Emotion Classification Accuracy on the Validation set: 0.469490110874176

Running time for training the FNN: 26.87890362739563 ms

Parameters for the model:

{'name': 'sequential_2', 'layers': [{'class_name': 'InputLayer', 'config':
{'batch_input_shape': (None, 2304), 'dtype': 'float32', 'sparse': False,
'ragged': False, 'name': 'first_hidden_layer_input'}}, {'class_name': 'Dense',
'config': {'name': 'first_hidden_layer', 'trainable': True, 'batch_input_shape':
(None, 2304), 'dtype': 'float32', 'units': 2000, 'activation': 'elu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
```

```
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dense', 'config': {'name': 'second_hidden_layer',
'trainable': True, 'dtype': 'float32', 'units': 1000, 'activation': 'elu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dense', 'config': {'name': 'third_hidden_layer',
'trainable': True, 'dtype': 'float32', 'units': 500, 'activation': 'elu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dropout', 'config': {'name': 'dropout_1', 'trainable':
True, 'dtype': 'float32', 'rate': 0.25, 'noise_shape': None, 'seed': None}},
{'class_name': 'Dense', 'config': {'name': 'dense_2', 'trainable': True,
'dtype': 'float32', 'units': 7, 'activation': 'softmax', 'use_bias': True,
'kernel_initializer': {'class_name': 'GlorotUniform', 'config': {'seed': None}},
'bias_initializer': {'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer':
None, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}]}

Model: "sequential_2"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 first_hidden_layer (Dense)  (None, 2000)              4610000

 second_hidden_layer (Dense)  (None, 1000)             2001000

 third_hidden_layer (Dense)  (None, 500)               500500

 dropout_1 (Dropout)         (None, 500)               0

 dense_2 (Dense)             (None, 7)                 3507

=================================================================
Total params: 7,115,007
Trainable params: 7,115,007
Non-trainable params: 0
_________________________________________________________________
None

Number of Epochs used to train the model:  20
```

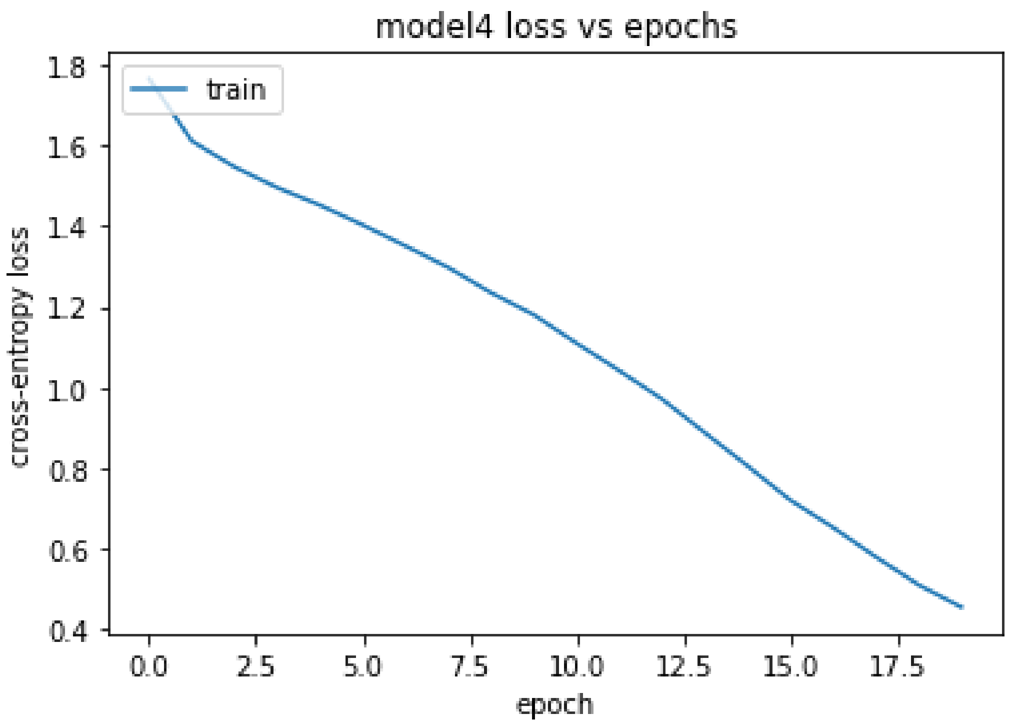

model3 loss vs epochs
train
cross-entropy loss
epoch
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5

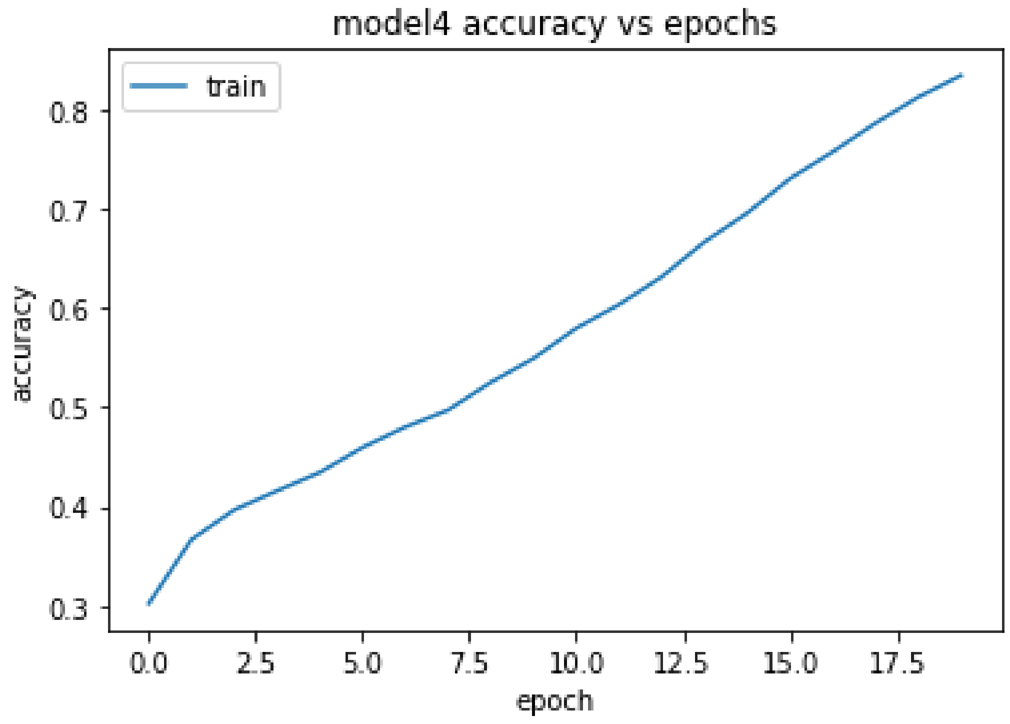

model3 accuracy vs epochs
train
accuracy
epoch
0.8
0.7
0.6
0.5
0.4
0.3
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5

```
Required details for model4

898/898 [==============================] - 5s 5ms/step - loss: 0.3394 -
accuracy: 0.8814
Emotion Classification Accuracy on the Training set: 0.8813612461090088

113/113 [==============================] - 1s 5ms/step - loss: 2.5049 -
accuracy: 0.4531
Emotion Classification Accuracy on the Validation set: 0.45305100083351135

Running time for training the FNN: 29.2670316696167 ms

Parameters for the model:
```

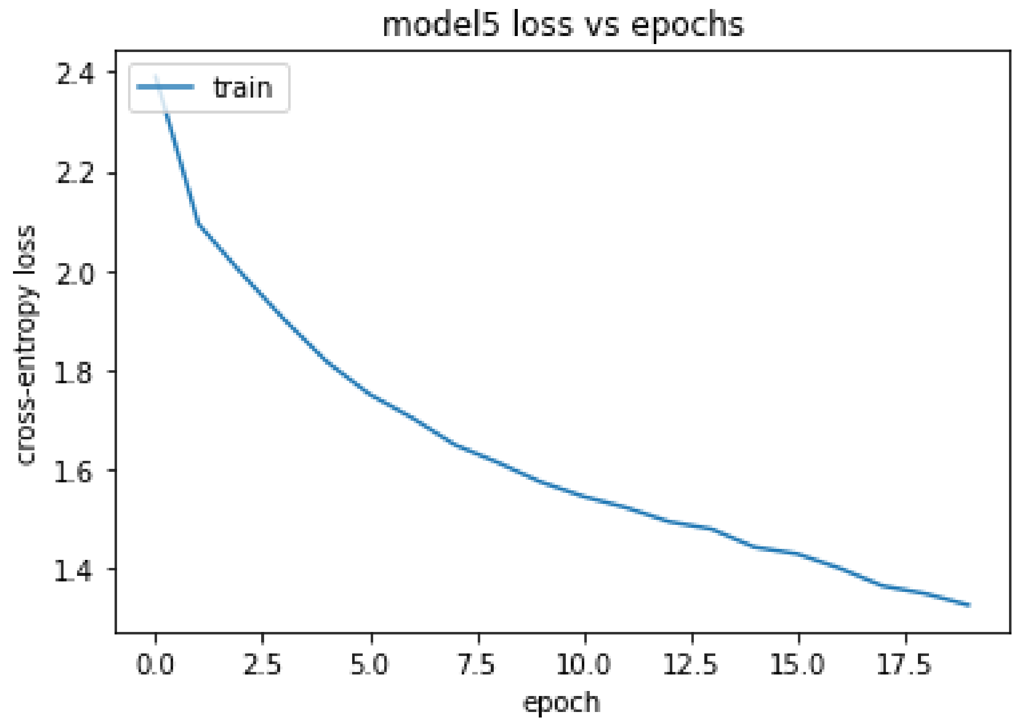
{'name': 'sequential_3', 'layers': [{'class_name': 'InputLayer', 'config':
{'batch_input_shape': (None, 2304), 'dtype': 'float32', 'sparse': False,
'ragged': False, 'name': 'first_hidden_layer_input'}}, {'class_name': 'Dense',
'config': {'name': 'first_hidden_layer', 'trainable': True, 'batch_input_shape':
(None, 2304), 'dtype': 'float32', 'units': 2000, 'activation': 'elu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dense', 'config': {'name': 'second_hidden_layer',
'trainable': True, 'dtype': 'float32', 'units': 1000, 'activation': 'elu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dense', 'config': {'name': 'third_hidden_layer',
'trainable': True, 'dtype': 'float32', 'units': 500, 'activation': 'elu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dense', 'config': {'name': 'fourth_hidden_layer',
'trainable': True, 'dtype': 'float32', 'units': 250, 'activation': 'elu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dense', 'config': {'name': 'fifth_hidden_layer',
'trainable': True, 'dtype': 'float32', 'units': 784, 'activation': 'relu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':

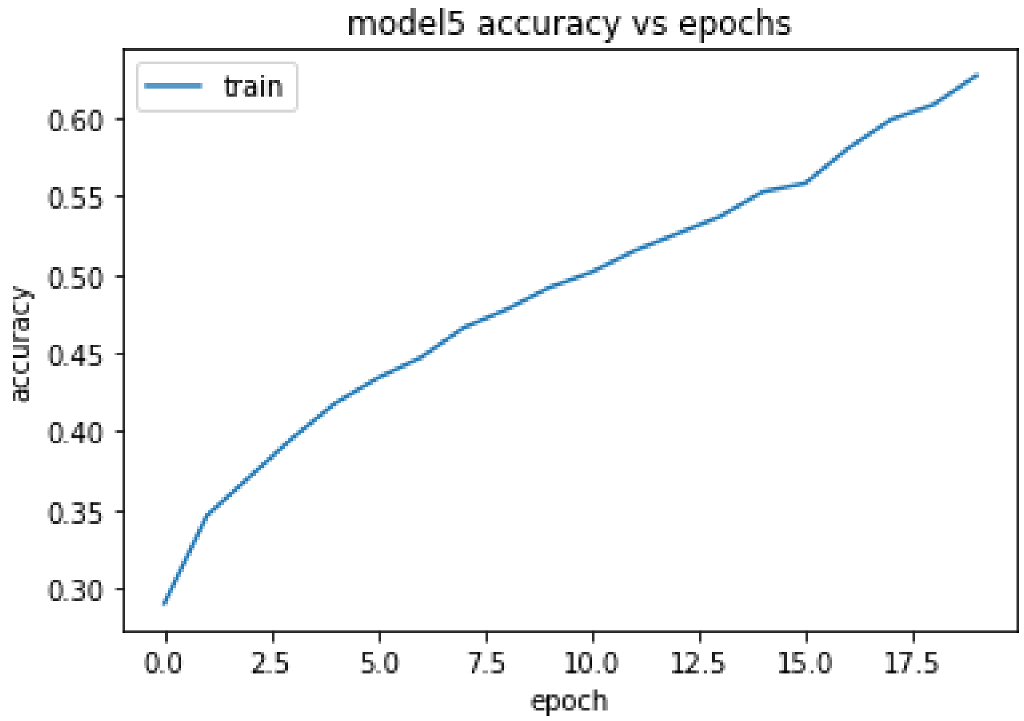
```
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dropout', 'config': {'name': 'dropout_2', 'trainable':
True, 'dtype': 'float32', 'rate': 0.25, 'noise_shape': None, 'seed': None}},
{'class_name': 'Dense', 'config': {'name': 'dense_3', 'trainable': True,
'dtype': 'float32', 'units': 7, 'activation': 'softmax', 'use_bias': True,
'kernel_initializer': {'class_name': 'GlorotUniform', 'config': {'seed': None}},
'bias_initializer': {'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer':
None, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}]}

Model: "sequential_3"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 first_hidden_layer (Dense)  (None, 2000)              4610000

 second_hidden_layer (Dense)  (None, 1000)             2001000

 third_hidden_layer (Dense)  (None, 500)               500500

 fourth_hidden_layer (Dense)  (None, 250)              125250

 fifth_hidden_layer (Dense)  (None, 784)               196784

 dropout_2 (Dropout)         (None, 784)               0

 dense_3 (Dense)             (None, 7)                 5495

=================================================================
Total params: 7,439,029
Trainable params: 7,439,029
Non-trainable params: 0
_________________________________________________________________
None

Number of Epochs used to train the model:  20
```


model4 loss vs epochs
train
cross-entropy loss
epoch
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5


model4 accuracy vs epochs
train
accuracy
epoch
0.8
0.7
0.6
0.5
0.4
0.3
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5

```
Required details for model5

898/898 [==============================] - 5s 6ms/step - loss: 1.2149 -
accuracy: 0.6733
Emotion Classification Accuracy on the Training set: 0.6732732057571411

113/113 [==============================] - 1s 6ms/step - loss: 1.9507 -
accuracy: 0.4478
Emotion Classification Accuracy on the Validation set: 0.4477570354938507

Running time for training the FNN: 32.77064371109009 ms

Parameters for the model:

{'name': 'sequential_4', 'layers': [{'class_name': 'InputLayer', 'config':
{'batch_input_shape': (None, 2304), 'dtype': 'float32', 'sparse': False,
'ragged': False, 'name': 'first_hidden_layer_input'}}, {'class_name': 'Dense',
'config': {'name': 'first_hidden_layer', 'trainable': True, 'batch_input_shape':
(None, 2304), 'dtype': 'float32', 'units': 2000, 'activation': 'elu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': {'class_name': 'L2', 'config': {'l2':
9.999999747378752e-05}}, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}, {'class_name': 'Dense',
'config': {'name': 'second_hidden_layer', 'trainable': True, 'dtype': 'float32',
'units': 1000, 'activation': 'elu', 'use_bias': True, 'kernel_initializer':
{'class_name': 'GlorotUniform', 'config': {'seed': None}}, 'bias_initializer':
{'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer': {'class_name':
'L2', 'config': {'l2': 9.999999747378752e-05}}, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dense', 'config': {'name': 'third_hidden_layer',
'trainable': True, 'dtype': 'float32', 'units': 500, 'activation': 'elu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': {'class_name': 'L2', 'config': {'l2':
9.999999747378752e-05}}, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}, {'class_name': 'Dense',
'config': {'name': 'fourth_hidden_layer', 'trainable': True, 'dtype': 'float32',
'units': 250, 'activation': 'elu', 'use_bias': True, 'kernel_initializer':
{'class_name': 'GlorotUniform', 'config': {'seed': None}}, 'bias_initializer':
{'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer': {'class_name':
'L2', 'config': {'l2': 9.999999747378752e-05}}, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dropout', 'config': {'name': 'dropout_3', 'trainable':
True, 'dtype': 'float32', 'rate': 0.25, 'noise_shape': None, 'seed': None}},
{'class_name': 'Dense', 'config': {'name': 'dense_4', 'trainable': True,
'dtype': 'float32', 'units': 7, 'activation': 'softmax', 'use_bias': True,
'kernel_initializer': {'class_name': 'GlorotUniform', 'config': {'seed': None}},
'bias_initializer': {'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer':
None, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}]}

Model: "sequential_4"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 first_hidden_layer (Dense)  (None, 2000)              4610000

 second_hidden_layer (Dense)  (None, 1000)             2001000

 third_hidden_layer (Dense)  (None, 500)               500500

 fourth_hidden_layer (Dense)  (None, 250)              125250

 dropout_3 (Dropout)         (None, 250)               0

 dense_4 (Dense)             (None, 7)                 1757

=================================================================
Total params: 7,238,507
Trainable params: 7,238,507
Non-trainable params: 0
_________________________________________________________________
None

Number of Epochs used to train the model:  20
```


model5 loss vs epochs
train
cross-entropy loss
epoch
2.4
2.2
2.0
1.8
1.6
1.4
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5


model5 accuracy vs epochs
train
accuracy
epoch
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.0
2.5
5.0
7.5
10.0
12.5
15.0
17.5

1.2.8 Answer:

Five different FNN models have been trained on the training dataset and evaluated on the validation dataset. The required details are shown above. The values in a tabular form is shown below:

Model name	Accuracy on Train dataset (%)	Accuracy on Validation dataset (%)	Training Time (ms)	Parameters Count
model1	94.28	47.34	26.95	5,230,463
model2	88.36	45.44	24.50	5,154,807
model3	90.70	46.95	26.87	7,115,007
model4	88.14	45.31	29.26	7,439,029
model5	67.33	44.78	32.77	7,238,507

1.2.9 (c.ii) (1 point) Run the best model that was found based on the validation set from question (c.i) on the testing set. Report the emotion classification accuracy on the testing set.

1.2.10 Answer:

1.2.11 The best model that was found based on the validation set is:

[12]:
```
# print (validation_performances)
max_validation=validation_performances.index(max(validation_performances))
print (model_names[max_validation])
print (models[max_validation].summary())

print("Emotion Classification Accuracy on the Validation set for the model: {}␣
↪".format(validation_performances[max_validation]))
```

```
model1
Model: "sequential"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 first_hidden_layer (Dense)  (None, 1568)              3614240

 second_hidden_layer (Dense)  (None, 784)              1230096

 third_hidden_layer (Dense)  (None, 392)               307720

 fourth_hidden_layer (Dense)  (None, 196)              77028

 dense (Dense)               (None, 7)                 1379

=================================================================
Total params: 5,230,463
```

```
Trainable params: 5,230,463
Non-trainable params: 0
_________________________________________________________________
None
Emotion Classification Accuracy on the Validation set for the model:
0.4733909070491791
```

1.2.12 The emotion classification accuracy of the model on the testing dataset is:

[13]:
```
test_emotions=np.array(list(test_data['emotion']))
test_pixels=np.array(list(test_data['pixels_int']))

flatten_test_images = test_pixels

test_performance = models[max_validation].evaluate(flatten_test_images,␣
 ↪to_categorical(test_emotions))
print("Emotion Classification Accuracy on the Testing set: {0}".
 ↪format(test_performance[1]))
```

```
113/113 [==============================] - 1s 5ms/step - loss: 3.2297 -
accuracy: 0.4728
Emotion Classification Accuracy on the Testing set: 0.47283366322517395
```

1.2.13 (d) (4 points) Image classification with CNNs: In this part, you will use a convolutional neural network (CNN) to perform the emotion classification task.

[14]:
```
from tensorflow.keras.layers import Conv2D, Flatten, MaxPooling2D



common_features_1 = [Conv2D(32, kernel_size=3, activation='relu',␣
 ↪input_shape=(48,48,1)),
            Conv2D(32, kernel_size=3, activation='relu'),
            MaxPooling2D(pool_size=(2,2)),
            Conv2D(64, kernel_size=3, activation='relu'),
            Conv2D(64, kernel_size=3, activation='relu'),
            MaxPooling2D(pool_size=(2,2)), Flatten(),]
classifier_1 = [Dense(512, activation='relu'), Dense(len(emotions),␣
 ↪activation='softmax'),]

cnn_model_1 = Sequential(common_features_1+classifier_1)



common_features_2 = [Conv2D(64, kernel_size=3, activation='relu',␣
 ↪input_shape=(48,48,1),use_bias=True),
            Conv2D(64, kernel_size=3, activation='relu',use_bias=True),
            MaxPooling2D(pool_size=(2,2)),
            Conv2D(128, kernel_size=3, activation='relu',use_bias=True, ␣
 ↪kernel_regularizer =tf.keras.regularizers.l2( l=0.001)),
            Conv2D(128, kernel_size=3, activation='relu',use_bias=True, ␣
 ↪kernel_regularizer =tf.keras.regularizers.l2( l=0.001)),
            MaxPooling2D(pool_size=(2,2)), Flatten(),]
classifier_2 = [Dense(512, activation='relu',use_bias=True,  kernel_regularizer␣
 ↪=tf.keras.regularizers.l2( l=0.01)), Dense(len(emotions),␣
 ↪activation='softmax',use_bias=True),]

cnn_model_2 = Sequential(common_features_2+classifier_2)



common_features_3 = [Conv2D(64, kernel_size=3,␣
 ↪activation='elu',input_shape=(48,48,1),use_bias=True),
            Conv2D(64, kernel_size=3,␣
 ↪activation='elu',padding='same',use_bias=True),
            MaxPooling2D(pool_size=(2,2)),
            Conv2D(128, kernel_size=3,␣
 ↪activation='elu',padding='same',use_bias=True),
            MaxPooling2D(pool_size=(2,2)),
            Conv2D(128, kernel_size=3, activation='elu', strides=(2,␣
 ↪2),padding='same',use_bias=True,  kernel_regularizer =tf.keras.regularizers.
 ↪l1( l=0.001)),
            Conv2D(128, kernel_size=3, activation='elu', strides=(2,␣
 ↪2),padding='same',use_bias=True, kernel_regularizer =tf.keras.regularizers.
 ↪l1( l=0.001)),
            MaxPooling2D(pool_size=(2,2)), Flatten(),]
classifier_3 = [Dense(512, activation='elu',use_bias=True,  kernel_regularizer␣
 ↪=tf.keras.regularizers.l1( l=0.01)),Dropout(0.25), Dense(len(emotions),␣
 ↪activation='softmax',use_bias=True),]

cnn_model_3 = Sequential(common_features_3+classifier_3)
```

[15]:
```
# print(cnn_model_1.summary())  # Compare number of parameteres against FFN

time_callback = TimeHistory()
cnn_model_1.compile(optimizer='adam',␣
 ↪loss='categorical_crossentropy',metrics=['accuracy'],)
cnn_model_2.compile(optimizer='adam',␣
 ↪loss='categorical_crossentropy',metrics=['accuracy'],)
cnn_model_3.compile(optimizer='adam',␣
 ↪loss='categorical_crossentropy',metrics=['accuracy'],)
time_to_train_cnn=[]

train_images_3d = flatten_train_images.
 ↪reshape(len(flatten_train_images),48,48,1)
```

```
test_images_3d = flatten_test_images.reshape(len(flatten_test_images),48,48,1)


cnn_history_1=cnn_model_1.fit(train_images_3d, to_categorical(train_emotions),␣
 ↪epochs=15, batch_size=256,callbacks = [time_callback])
time_to_train_cnn.append(time_callback.times)
cnn_history_2=cnn_model_2.fit(train_images_3d, to_categorical(train_emotions),␣
 ↪epochs=20, batch_size=256,callbacks = [time_callback])
time_to_train_cnn.append(time_callback.times)
cnn_history_3=cnn_model_3.fit(train_images_3d, to_categorical(train_emotions),␣
 ↪epochs=20, batch_size=256,callbacks = [time_callback])
time_to_train_cnn.append(time_callback.times)
```

```
Epoch 1/15
  6/113 [>…] - ETA: 7s - loss: 1.8666 - accuracy:
0.2181WARNING:tensorflow:Callback method `on_train_batch_end` is slow compared
to the batch time (batch time: 0.0308s vs `on_train_batch_end` time: 0.0325s).
Check your callbacks.
113/113 [==============================] - 36s 70ms/step - loss: 1.6138 -
accuracy: 0.3642
Epoch 2/15
113/113 [==============================] - 8s 69ms/step - loss: 1.3458 -
accuracy: 0.4901
Epoch 3/15
113/113 [==============================] - 8s 69ms/step - loss: 1.1907 -
accuracy: 0.5498
Epoch 4/15
113/113 [==============================] - 8s 70ms/step - loss: 1.0795 -
accuracy: 0.5944
Epoch 5/15
113/113 [==============================] - 8s 69ms/step - loss: 0.9614 -
accuracy: 0.6458
Epoch 6/15
113/113 [==============================] - 8s 68ms/step - loss: 0.8132 -
accuracy: 0.7065
Epoch 7/15
113/113 [==============================] - 8s 68ms/step - loss: 0.6542 -
accuracy: 0.7669
Epoch 8/15
113/113 [==============================] - 8s 68ms/step - loss: 0.4602 -
accuracy: 0.8402
Epoch 9/15
113/113 [==============================] - 8s 69ms/step - loss: 0.2866 -
accuracy: 0.9036
Epoch 10/15
113/113 [==============================] - 8s 68ms/step - loss: 0.1756 -
accuracy: 0.9444
```

```
Epoch 11/15
113/113 [==============================] - 8s 69ms/step - loss: 0.1143 -
accuracy: 0.9666
Epoch 12/15
113/113 [==============================] - 8s 68ms/step - loss: 0.0887 -
accuracy: 0.9782
Epoch 13/15
113/113 [==============================] - 8s 69ms/step - loss: 0.0805 -
accuracy: 0.9792
Epoch 14/15
113/113 [==============================] - 8s 69ms/step - loss: 0.0640 -
accuracy: 0.9859
Epoch 15/15
113/113 [==============================] - 8s 69ms/step - loss: 0.0452 -
accuracy: 0.9910
Epoch 1/20
  6/113 [>…] - ETA: 14s - loss: 9.2549 - accuracy:
0.2122WARNING:tensorflow:Callback method `on_train_batch_end` is slow compared
to the batch time (batch time: 0.0470s vs `on_train_batch_end` time: 0.0726s).
Check your callbacks.
113/113 [==============================] - 18s 137ms/step - loss: 2.4422 -
accuracy: 0.3194
Epoch 2/20
113/113 [==============================] - 15s 135ms/step - loss: 1.6292 -
accuracy: 0.4212
Epoch 3/20
113/113 [==============================] - 15s 135ms/step - loss: 1.5323 -
accuracy: 0.4656
Epoch 4/20
113/113 [==============================] - 15s 135ms/step - loss: 1.4733 -
accuracy: 0.4891
Epoch 5/20
113/113 [==============================] - 15s 135ms/step - loss: 1.4385 -
accuracy: 0.5104
Epoch 6/20
113/113 [==============================] - 15s 134ms/step - loss: 1.4073 -
accuracy: 0.5235
Epoch 7/20
113/113 [==============================] - 15s 134ms/step - loss: 1.3780 -
accuracy: 0.5388
Epoch 8/20
113/113 [==============================] - 15s 134ms/step - loss: 1.3672 -
accuracy: 0.5519
Epoch 9/20
113/113 [==============================] - 15s 134ms/step - loss: 1.3364 -
accuracy: 0.5667
Epoch 10/20
113/113 [==============================] - 15s 134ms/step - loss: 1.3279 -
```

```
accuracy: 0.5757
Epoch 11/20
113/113 [==============================] - 15s 135ms/step - loss: 1.3068 -
accuracy: 0.5918
Epoch 12/20
113/113 [==============================] - 15s 135ms/step - loss: 1.2874 -
accuracy: 0.6038
Epoch 13/20
113/113 [==============================] - 15s 135ms/step - loss: 1.2769 -
accuracy: 0.6114
Epoch 14/20
113/113 [==============================] - 15s 135ms/step - loss: 1.2487 -
accuracy: 0.6278
Epoch 15/20
113/113 [==============================] - 15s 135ms/step - loss: 1.2384 -
accuracy: 0.6353
Epoch 16/20
113/113 [==============================] - 15s 135ms/step - loss: 1.2262 -
accuracy: 0.6502
Epoch 17/20
113/113 [==============================] - 15s 135ms/step - loss: 1.2112 -
accuracy: 0.6625
Epoch 18/20
113/113 [==============================] - 15s 134ms/step - loss: 1.2522 -
accuracy: 0.6580
Epoch 19/20
113/113 [==============================] - 15s 135ms/step - loss: 1.1952 -
accuracy: 0.6769
Epoch 20/20
113/113 [==============================] - 15s 135ms/step - loss: 1.1664 -
accuracy: 0.6935
Epoch 1/20
  6/113 [>…] - ETA: 15s - loss: 38.8504 - accuracy:
0.2337WARNING:tensorflow:Callback method `on_train_batch_end` is slow compared
to the batch time (batch time: 0.0521s vs `on_train_batch_end` time: 0.0814s).
Check your callbacks.
113/113 [==============================] - 18s 141ms/step - loss: 12.8331 -
accuracy: 0.2555
Epoch 2/20
113/113 [==============================] - 16s 138ms/step - loss: 1.9257 -
accuracy: 0.2942
Epoch 3/20
113/113 [==============================] - 16s 138ms/step - loss: 1.8848 -
accuracy: 0.3161
Epoch 4/20
113/113 [==============================] - 16s 138ms/step - loss: 1.8755 -
accuracy: 0.3279
Epoch 5/20
```

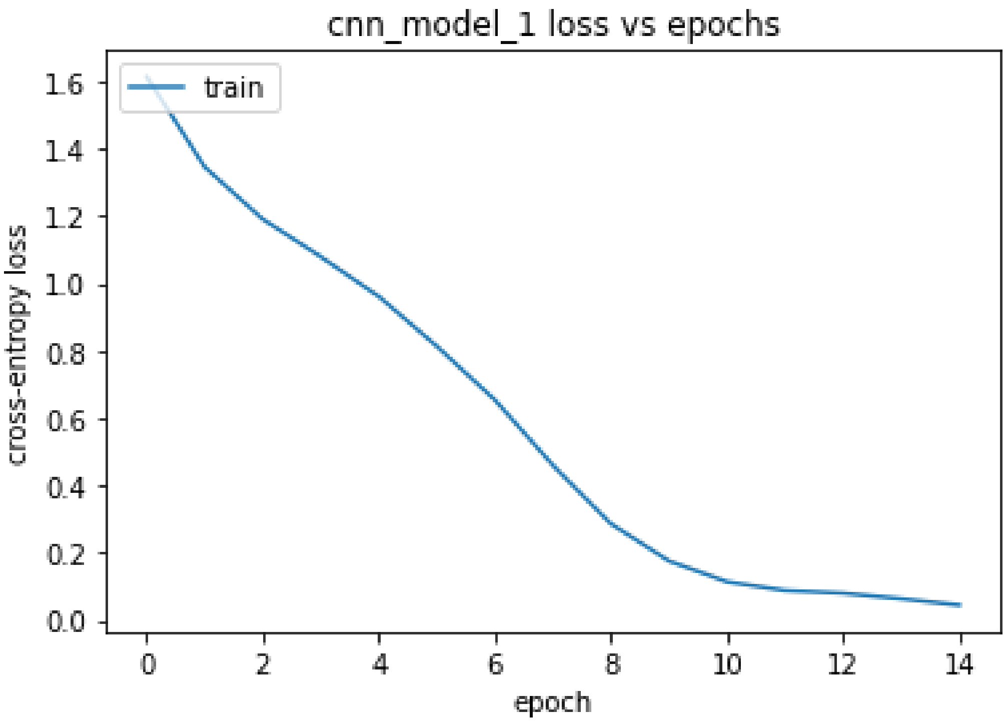
```
113/113 [==============================] - 16s 138ms/step - loss: 1.8652 -
accuracy: 0.3353
Epoch 6/20
113/113 [==============================] - 16s 139ms/step - loss: 1.8564 -
accuracy: 0.3427
Epoch 7/20
113/113 [==============================] - 16s 139ms/step - loss: 1.8179 -
accuracy: 0.3494
Epoch 8/20
113/113 [==============================] - 16s 139ms/step - loss: 1.8348 -
accuracy: 0.3554
Epoch 9/20
113/113 [==============================] - 16s 139ms/step - loss: 1.8081 -
accuracy: 0.3645
Epoch 10/20
113/113 [==============================] - 16s 139ms/step - loss: 1.7868 -
accuracy: 0.3721
Epoch 11/20
113/113 [==============================] - 16s 140ms/step - loss: 1.7774 -
accuracy: 0.3831
Epoch 12/20
113/113 [==============================] - 16s 140ms/step - loss: 1.7781 -
accuracy: 0.3923
Epoch 13/20
113/113 [==============================] - 16s 140ms/step - loss: 1.7670 -
accuracy: 0.3960
Epoch 14/20
113/113 [==============================] - 16s 140ms/step - loss: 1.7509 -
accuracy: 0.4016
Epoch 15/20
113/113 [==============================] - 16s 140ms/step - loss: 1.7190 -
accuracy: 0.4105
Epoch 16/20
113/113 [==============================] - 16s 139ms/step - loss: 1.7114 -
accuracy: 0.4138
Epoch 17/20
113/113 [==============================] - 16s 139ms/step - loss: 1.6906 -
accuracy: 0.4200
Epoch 18/20
113/113 [==============================] - 16s 139ms/step - loss: 1.6791 -
accuracy: 0.4251
Epoch 19/20
113/113 [==============================] - 16s 139ms/step - loss: 1.6780 -
accuracy: 0.4305
Epoch 20/20
113/113 [==============================] - 16s 139ms/step - loss: 1.6748 -
accuracy: 0.4347
```

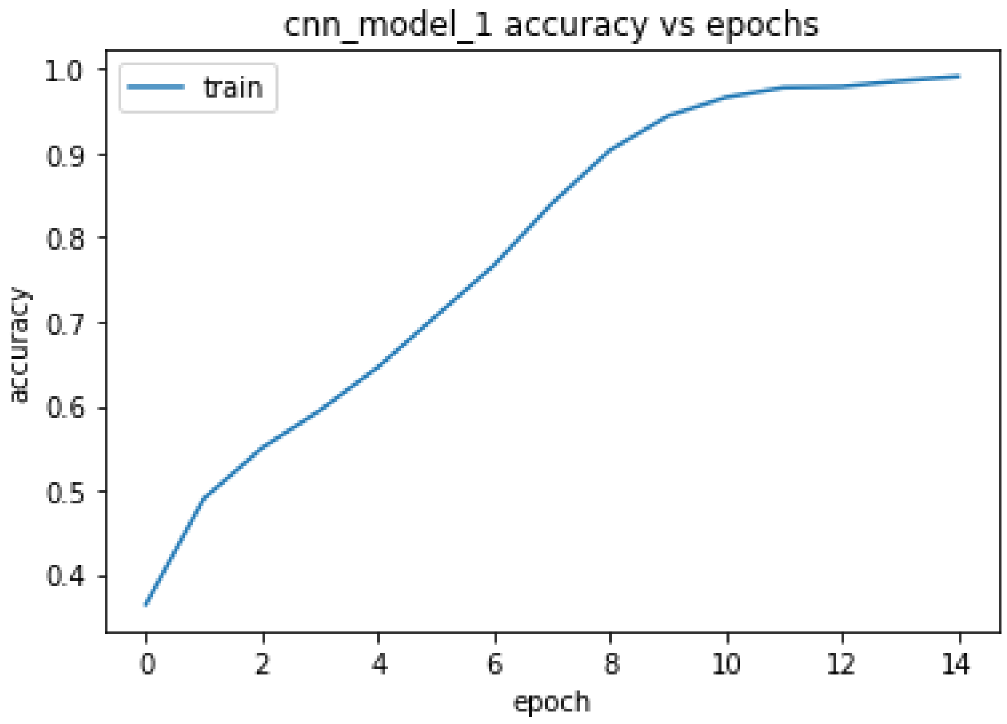
1.2.14 (d.i) (3 points) Experiment on the validation set with different CNN hyper-parameters, e.g. layers, filter size, stride size, activation function, dropout, weight regularization, etc. For each hyper-parameter combination that you have used, please report the following: (1) emotion classification accuracy on the training and validation sets; (2) running time for training the FNN; (3) parameters for each CNN. How do these metrics compare to the FNN?

[30]:
```
validation_images_3d = flatten_validation_images.
 ↪reshape(len(flatten_validation_images),48,48,1)

validation_performances_cnn=[]
cnn_models=[cnn_model_1,cnn_model_2,cnn_model_3]
cnn_model_names=['cnn_model_1','cnn_model_2','cnn_model_3']
cnn_histories=[cnn_history_1,cnn_history_2,cnn_history_3]
for i in range(len(cnn_models)):
  print (" ")
  print ("Required details for {}".format(cnn_model_names[i]))
  print (" ")
  performance1_cnn = cnn_models[i].evaluate(train_images_3d,␣
 ↪to_categorical(train_emotions))
  print("Emotion Classification Accuracy on the Training set: {0}".
 ↪format(performance1_cnn[1]))
  print (" ")
  performance2_cnn = cnn_models[i].evaluate(validation_images_3d,␣
 ↪to_categorical(validation_emotions))
  validation_performances_cnn.append(performance2_cnn[1])
  print("Emotion Classification Accuracy on the Validation set: {0}".
 ↪format(performance2_cnn[1]))
  print (" ")
  print ("Running time for training the CNN: {} ms".
 ↪format(str(time_to_train_cnn[i][0])))
  print (" ")
  print ("Parameters for the model:")
  print (" ")
  print (cnn_models[i].get_config())
  print (" ")
  print (cnn_models[i].summary())


  print (" ")
  print('Number of Epochs used to train the model: ', len(cnn_histories[i].
 ↪history['loss']))



  print(" ")
  # print(history.history.keys())
  # summarize history for loss
  plt.plot(cnn_histories[i].history['loss'])
  plt.title('{} loss vs epochs'.format(cnn_model_names[i]))
  plt.ylabel('cross-entropy loss')
  plt.xlabel('epoch')
  plt.legend(['train'], loc='upper left')
  plt.show()
  # summarize history for accuracy
  plt.plot(cnn_histories[i].history['accuracy'])
  plt.title('{} accuracy vs epochs'.format(cnn_model_names[i]))
  plt.ylabel('accuracy')
  plt.xlabel('epoch')
  plt.legend(['train'], loc='upper left')
  plt.show()

  print (" ")
  print (" ")






# performance = cnn_model.evaluate(test_images_3d,␣
 ↪to_categorical(test_emotions))

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

```
Required details for cnn_model_1

898/898 [==============================] - 8s 9ms/step - loss: 0.0309 -
accuracy: 0.9948
Emotion Classification Accuracy on the Training set: 0.9947751760482788

113/113 [==============================] - 1s 9ms/step - loss: 2.9449 -
accuracy: 0.5737
Emotion Classification Accuracy on the Validation set: 0.5736973881721497

Running time for training the CNN: 144.84634375572205 ms

Parameters for the model:

{'name': 'sequential_5', 'layers': [{'class_name': 'InputLayer', 'config':
{'batch_input_shape': (None, 48, 48, 1), 'dtype': 'float32', 'sparse': False,
'ragged': False, 'name': 'conv2d_input'}}, {'class_name': 'Conv2D', 'config':
{'name': 'conv2d', 'trainable': True, 'batch_input_shape': (None, 48, 48, 1),
'dtype': 'float32', 'filters': 32, 'kernel_size': (3, 3), 'strides': (1, 1),
'padding': 'valid', 'data_format': 'channels_last', 'dilation_rate': (1, 1),
'groups': 1, 'activation': 'relu', 'use_bias': True, 'kernel_initializer':
{'class_name': 'GlorotUniform', 'config': {'seed': None}}, 'bias_initializer':
{'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer': None,
'bias_regularizer': None, 'activity_regularizer': None, 'kernel_constraint':
None, 'bias_constraint': None}}, {'class_name': 'Conv2D', 'config': {'name':
'conv2d_1', 'trainable': True, 'dtype': 'float32', 'filters': 32, 'kernel_size':
(3, 3), 'strides': (1, 1), 'padding': 'valid', 'data_format': 'channels_last',
'dilation_rate': (1, 1), 'groups': 1, 'activation': 'relu', 'use_bias': True,
'kernel_initializer': {'class_name': 'GlorotUniform', 'config': {'seed': None}},
'bias_initializer': {'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer':
None, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}, {'class_name':
'MaxPooling2D', 'config': {'name': 'max_pooling2d', 'trainable': True, 'dtype':
'float32', 'pool_size': (2, 2), 'padding': 'valid', 'strides': (2, 2),
'data_format': 'channels_last'}}, {'class_name': 'Conv2D', 'config': {'name':
'conv2d_2', 'trainable': True, 'dtype': 'float32', 'filters': 64, 'kernel_size':
(3, 3), 'strides': (1, 1), 'padding': 'valid', 'data_format': 'channels_last',
'dilation_rate': (1, 1), 'groups': 1, 'activation': 'relu', 'use_bias': True,
'kernel_initializer': {'class_name': 'GlorotUniform', 'config': {'seed': None}},
'bias_initializer': {'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer':
None, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}, {'class_name': 'Conv2D',
'config': {'name': 'conv2d_3', 'trainable': True, 'dtype': 'float32', 'filters':
64, 'kernel_size': (3, 3), 'strides': (1, 1), 'padding': 'valid', 'data_format':
'channels_last', 'dilation_rate': (1, 1), 'groups': 1, 'activation': 'relu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'MaxPooling2D', 'config': {'name': 'max_pooling2d_1',
'trainable': True, 'dtype': 'float32', 'pool_size': (2, 2), 'padding': 'valid',
'strides': (2, 2), 'data_format': 'channels_last'}}, {'class_name': 'Flatten',
'config': {'name': 'flatten', 'trainable': True, 'dtype': 'float32',
'data_format': 'channels_last'}}, {'class_name': 'Dense', 'config': {'name':
'dense_5', 'trainable': True, 'dtype': 'float32', 'units': 512, 'activation':
'relu', 'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Dense', 'config': {'name': 'dense_6', 'trainable': True,
'dtype': 'float32', 'units': 7, 'activation': 'softmax', 'use_bias': True,
'kernel_initializer': {'class_name': 'GlorotUniform', 'config': {'seed': None}},
'bias_initializer': {'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer':
None, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}]}

Model: "sequential_5"
```

```
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d (Conv2D)             (None, 46, 46, 32)        320

 conv2d_1 (Conv2D)           (None, 44, 44, 32)        9248

 max_pooling2d (MaxPooling2D  (None, 22, 22, 32)       0
 )

 conv2d_2 (Conv2D)           (None, 20, 20, 64)        18496

 conv2d_3 (Conv2D)           (None, 18, 18, 64)        36928

 max_pooling2d_1 (MaxPooling  (None, 9, 9, 64)         0
 2D)

 flatten (Flatten)           (None, 5184)              0

 dense_5 (Dense)             (None, 512)               2654720

 dense_6 (Dense)             (None, 7)                 3591

=================================================================
Total params: 2,723,303
Trainable params: 2,723,303
Non-trainable params: 0
_________________________________________________________________
None

Number of Epochs used to train the model:  15
```


cnn_model_1 loss vs epochs
train
cross-entropy loss
epoch
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
0
2
4
6
8
10
12
14

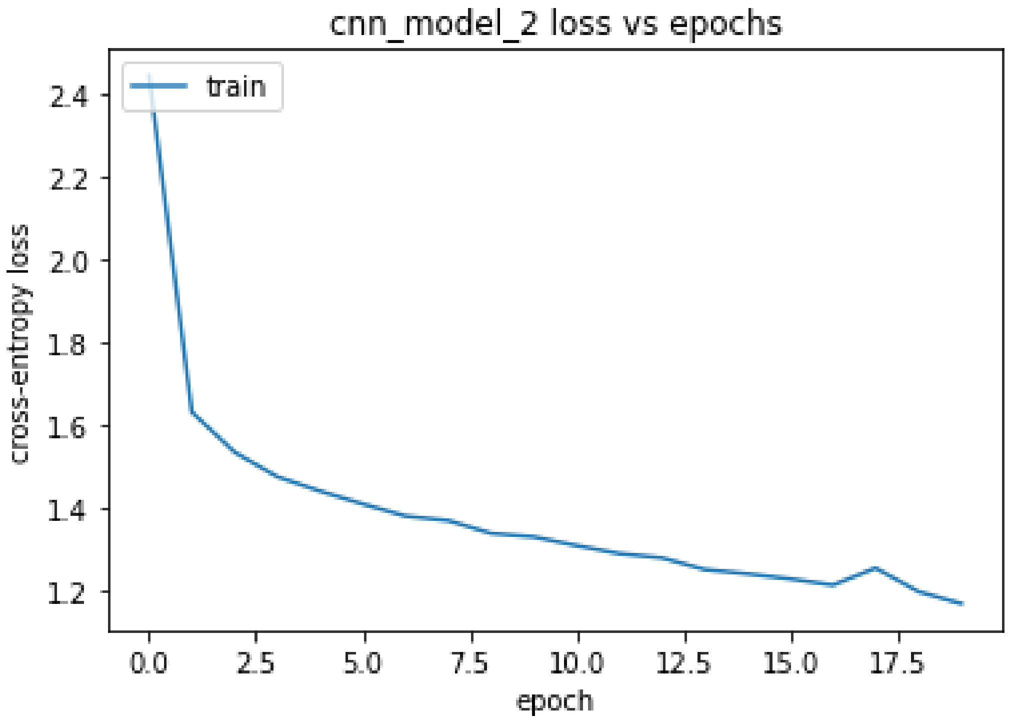

cnn_model_1 accuracy vs epochs
train
accuracy
epoch
0.4
0.5
0.6
0.7
0.8
0.9
1.0
0
2
4
6
8
10
12
14

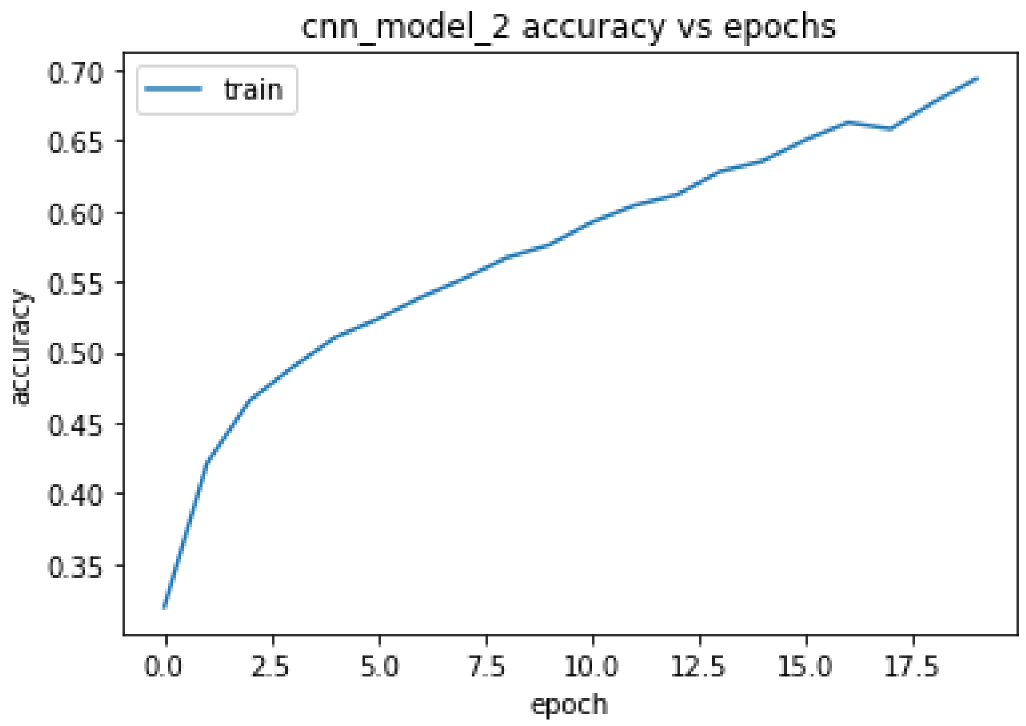
```
Required details for cnn_model_2

898/898 [==============================] - 10s 11ms/step - loss: 1.0117 -
accuracy: 0.7653
Emotion Classification Accuracy on the Training set: 0.7652652263641357

113/113 [==============================] - 1s 11ms/step - loss: 1.5836 -
accuracy: 0.5587
Emotion Classification Accuracy on the Validation set: 0.5586514472961426

Running time for training the CNN: 307.31507754325867 ms

Parameters for the model:
```

{'name': 'sequential_6', 'layers': [{'class_name': 'InputLayer', 'config':
{'batch_input_shape': (None, 48, 48, 1), 'dtype': 'float32', 'sparse': False,
'ragged': False, 'name': 'conv2d_4_input'}}, {'class_name': 'Conv2D', 'config':
{'name': 'conv2d_4', 'trainable': True, 'batch_input_shape': (None, 48, 48, 1),
'dtype': 'float32', 'filters': 64, 'kernel_size': (3, 3), 'strides': (1, 1),
'padding': 'valid', 'data_format': 'channels_last', 'dilation_rate': (1, 1),
'groups': 1, 'activation': 'relu', 'use_bias': True, 'kernel_initializer':
{'class_name': 'GlorotUniform', 'config': {'seed': None}}, 'bias_initializer':
{'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer': None,
'bias_regularizer': None, 'activity_regularizer': None, 'kernel_constraint':
None, 'bias_constraint': None}}, {'class_name': 'Conv2D', 'config': {'name':
'conv2d_5', 'trainable': True, 'dtype': 'float32', 'filters': 64, 'kernel_size':
(3, 3), 'strides': (1, 1), 'padding': 'valid', 'data_format': 'channels_last',
'dilation_rate': (1, 1), 'groups': 1, 'activation': 'relu', 'use_bias': True,
'kernel_initializer': {'class_name': 'GlorotUniform', 'config': {'seed': None}},
'bias_initializer': {'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer':
None, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}, {'class_name':
'MaxPooling2D', 'config': {'name': 'max_pooling2d_2', 'trainable': True,
'dtype': 'float32', 'pool_size': (2, 2), 'padding': 'valid', 'strides': (2, 2),
'data_format': 'channels_last'}}, {'class_name': 'Conv2D', 'config': {'name':
'conv2d_6', 'trainable': True, 'dtype': 'float32', 'filters': 128,
'kernel_size': (3, 3), 'strides': (1, 1), 'padding': 'valid', 'data_format':
'channels_last', 'dilation_rate': (1, 1), 'groups': 1, 'activation': 'relu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': {'class_name': 'L2', 'config': {'l2':
0.0010000000474974513}}, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}, {'class_name': 'Conv2D',
'config': {'name': 'conv2d_7', 'trainable': True, 'dtype': 'float32', 'filters':
128, 'kernel_size': (3, 3), 'strides': (1, 1), 'padding': 'valid',

```
'data_format': 'channels_last', 'dilation_rate': (1, 1), 'groups': 1,
'activation': 'relu', 'use_bias': True, 'kernel_initializer': {'class_name':
'GlorotUniform', 'config': {'seed': None}}, 'bias_initializer': {'class_name':
'Zeros', 'config': {}}, 'kernel_regularizer': {'class_name': 'L2', 'config':
{'l2': 0.0010000000474974513}}, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'MaxPooling2D', 'config': {'name': 'max_pooling2d_3',
'trainable': True, 'dtype': 'float32', 'pool_size': (2, 2), 'padding': 'valid',
'strides': (2, 2), 'data_format': 'channels_last'}}, {'class_name': 'Flatten',
'config': {'name': 'flatten_1', 'trainable': True, 'dtype': 'float32',
'data_format': 'channels_last'}}, {'class_name': 'Dense', 'config': {'name':
'dense_7', 'trainable': True, 'dtype': 'float32', 'units': 512, 'activation':
'relu', 'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': {'class_name': 'L2', 'config': {'l2':
0.009999999776482582}}, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}, {'class_name': 'Dense',
'config': {'name': 'dense_8', 'trainable': True, 'dtype': 'float32', 'units': 7,
'activation': 'softmax', 'use_bias': True, 'kernel_initializer': {'class_name':
'GlorotUniform', 'config': {'seed': None}}, 'bias_initializer': {'class_name':
'Zeros', 'config': {}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}]}

Model: "sequential_6"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_4 (Conv2D)           (None, 46, 46, 64)        640

 conv2d_5 (Conv2D)           (None, 44, 44, 64)        36928

 max_pooling2d_2 (MaxPooling  (None, 22, 22, 64)       0
 2D)

 conv2d_6 (Conv2D)           (None, 20, 20, 128)       73856

 conv2d_7 (Conv2D)           (None, 18, 18, 128)       147584

 max_pooling2d_3 (MaxPooling  (None, 9, 9, 128)        0
 2D)

 flatten_1 (Flatten)         (None, 10368)             0

 dense_7 (Dense)             (None, 512)               5308928

 dense_8 (Dense)             (None, 7)                 3591
```

```
=================================================================
Total params: 5,571,527
Trainable params: 5,571,527
Non-trainable params: 0
_________________________________________________________________
None

Number of Epochs used to train the model:  20
```





```
Required details for cnn_model_3

898/898 [==============================] - 10s 11ms/step - loss: 1.6395 -
accuracy: 0.4426
Emotion Classification Accuracy on the Training set: 0.442613810300827

113/113 [==============================] - 1s 11ms/step - loss: 1.6722 -
accuracy: 0.4271
Emotion Classification Accuracy on the Validation set: 0.42713847756385803

Running time for training the CNN: 316.84715700149536 ms

Parameters for the model:

{'name': 'sequential_7', 'layers': [{'class_name': 'InputLayer', 'config':
{'batch_input_shape': (None, 48, 48, 1), 'dtype': 'float32', 'sparse': False,
'ragged': False, 'name': 'conv2d_8_input'}}, {'class_name': 'Conv2D', 'config':
{'name': 'conv2d_8', 'trainable': True, 'batch_input_shape': (None, 48, 48, 1),
'dtype': 'float32', 'filters': 64, 'kernel_size': (3, 3), 'strides': (1, 1),
'padding': 'valid', 'data_format': 'channels_last', 'dilation_rate': (1, 1),
'groups': 1, 'activation': 'elu', 'use_bias': True, 'kernel_initializer':
```

{'class_name': 'GlorotUniform', 'config': {'seed': None}}, 'bias_initializer':
{'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer': None,
'bias_regularizer': None, 'activity_regularizer': None, 'kernel_constraint':
None, 'bias_constraint': None}}, {'class_name': 'Conv2D', 'config': {'name':
'conv2d_9', 'trainable': True, 'dtype': 'float32', 'filters': 64, 'kernel_size':
(3, 3), 'strides': (1, 1), 'padding': 'same', 'data_format': 'channels_last',
'dilation_rate': (1, 1), 'groups': 1, 'activation': 'elu', 'use_bias': True,
'kernel_initializer': {'class_name': 'GlorotUniform', 'config': {'seed': None}},
'bias_initializer': {'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer':
None, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}, {'class_name':
'MaxPooling2D', 'config': {'name': 'max_pooling2d_4', 'trainable': True,
'dtype': 'float32', 'pool_size': (2, 2), 'padding': 'valid', 'strides': (2, 2),
'data_format': 'channels_last'}}, {'class_name': 'Conv2D', 'config': {'name':
'conv2d_10', 'trainable': True, 'dtype': 'float32', 'filters': 128,
'kernel_size': (3, 3), 'strides': (1, 1), 'padding': 'same', 'data_format':
'channels_last', 'dilation_rate': (1, 1), 'groups': 1, 'activation': 'elu',
'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':
{}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'MaxPooling2D', 'config': {'name': 'max_pooling2d_5',
'trainable': True, 'dtype': 'float32', 'pool_size': (2, 2), 'padding': 'valid',
'strides': (2, 2), 'data_format': 'channels_last'}}, {'class_name': 'Conv2D',
'config': {'name': 'conv2d_11', 'trainable': True, 'dtype': 'float32',
'filters': 128, 'kernel_size': (3, 3), 'strides': (2, 2), 'padding': 'same',
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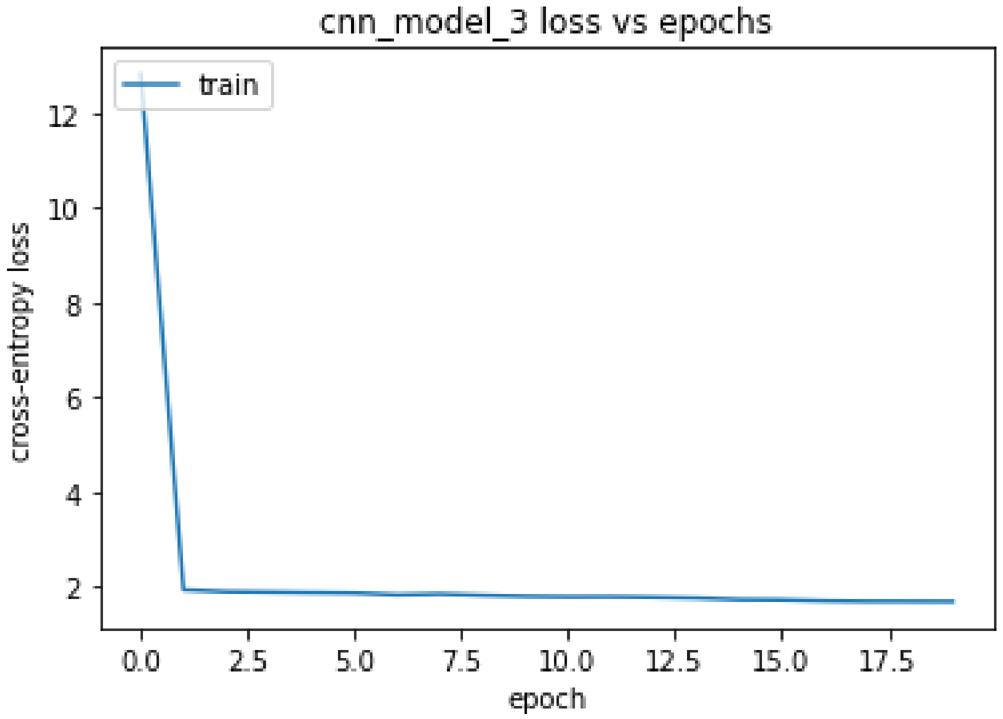
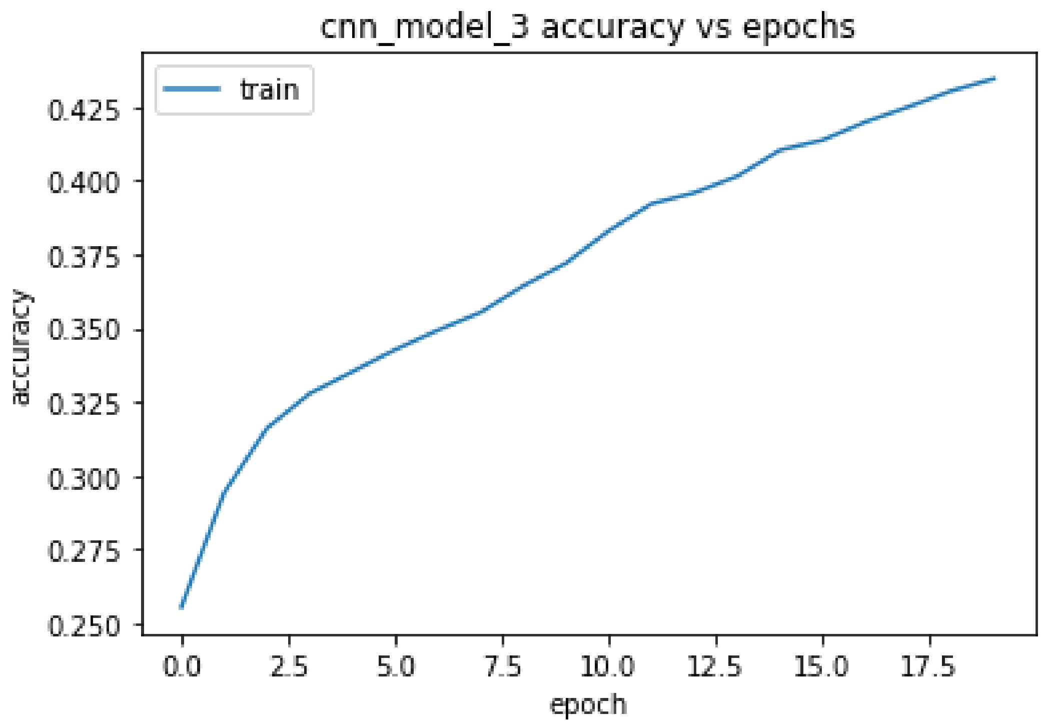
'GlorotUniform', 'config': {'seed': None}}, 'bias_initializer': {'class_name':
'Zeros', 'config': {}}, 'kernel_regularizer': {'class_name': 'L1', 'config':
{'l1': 0.0010000000474974513}}, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'Conv2D', 'config': {'name': 'conv2d_12', 'trainable':
True, 'dtype': 'float32', 'filters': 128, 'kernel_size': (3, 3), 'strides': (2,
2), 'padding': 'same', 'data_format': 'channels_last', 'dilation_rate': (1, 1),
'groups': 1, 'activation': 'elu', 'use_bias': True, 'kernel_initializer':
{'class_name': 'GlorotUniform', 'config': {'seed': None}}, 'bias_initializer':
{'class_name': 'Zeros', 'config': {}}, 'kernel_regularizer': {'class_name':
'L1', 'config': {'l1': 0.0010000000474974513}}, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}, {'class_name': 'MaxPooling2D', 'config': {'name': 'max_pooling2d_6',
'trainable': True, 'dtype': 'float32', 'pool_size': (2, 2), 'padding': 'valid',
'strides': (2, 2), 'data_format': 'channels_last'}}, {'class_name': 'Flatten',
'config': {'name': 'flatten_2', 'trainable': True, 'dtype': 'float32',
'data_format': 'channels_last'}}, {'class_name': 'Dense', 'config': {'name':
'dense_9', 'trainable': True, 'dtype': 'float32', 'units': 512, 'activation':
'elu', 'use_bias': True, 'kernel_initializer': {'class_name': 'GlorotUniform',
'config': {'seed': None}}, 'bias_initializer': {'class_name': 'Zeros', 'config':

```
{}}, 'kernel_regularizer': {'class_name': 'L1', 'config': {'l1':
0.009999999776482582}}, 'bias_regularizer': None, 'activity_regularizer': None,
'kernel_constraint': None, 'bias_constraint': None}}, {'class_name': 'Dropout',
'config': {'name': 'dropout_4', 'trainable': True, 'dtype': 'float32', 'rate':
0.25, 'noise_shape': None, 'seed': None}}, {'class_name': 'Dense', 'config':
{'name': 'dense_10', 'trainable': True, 'dtype': 'float32', 'units': 7,
'activation': 'softmax', 'use_bias': True, 'kernel_initializer': {'class_name':
'GlorotUniform', 'config': {'seed': None}}, 'bias_initializer': {'class_name':
'Zeros', 'config': {}}, 'kernel_regularizer': None, 'bias_regularizer': None,
'activity_regularizer': None, 'kernel_constraint': None, 'bias_constraint':
None}}]}

Model: "sequential_7"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d_8 (Conv2D)           (None, 46, 46, 64)        640

 conv2d_9 (Conv2D)           (None, 46, 46, 64)        36928

 max_pooling2d_4 (MaxPooling  (None, 23, 23, 64)       0
 2D)

 conv2d_10 (Conv2D)          (None, 23, 23, 128)       73856

 max_pooling2d_5 (MaxPooling  (None, 11, 11, 128)      0
 2D)

 conv2d_11 (Conv2D)          (None, 6, 6, 128)         147584

 conv2d_12 (Conv2D)          (None, 3, 3, 128)         147584

 max_pooling2d_6 (MaxPooling  (None, 1, 1, 128)        0
 2D)

 flatten_2 (Flatten)         (None, 128)               0

 dense_9 (Dense)             (None, 512)               66048

 dropout_4 (Dropout)         (None, 512)               0

 dense_10 (Dense)            (None, 7)                 3591

=================================================================
Total params: 476,231
Trainable params: 476,231
Non-trainable params: 0
_________________________________________________________________
```

```
None

Number of Epochs used to train the model:  20
```





1.2.15 Answer:

Three different CNN models have been trained on the training dataset and evaluated on the validation dataset. The required details are shown above. The values in a tabular form is shown below:

CNN Model number	Accuracy on Train dataset (%)	Accuracy on Validation dataset (%)	Training Time (ms)	Parameters Count
1	99.48	57.37	144.84 ms	2,723,303
2	76.53	55.87	307.31 ms	5,571,527
3	44.26	42.71	316.84 ms	476,231

As can be seen,

1. The accuracy on train, validation, and test dataset in higher in CNN models than in FNN models.
2. The number of parameters to train in a CNN model is also lesser than in FNN model.
3. It is taking more time to train a CNN model than a FNN model.

1.2.16 (d.ii) (1 point) Run the best model that was found based on the validation set from question (d.i) on the testing set. Report the emotion classification accuracy on the testing set. How does this metric compare to the FNN?

1.2.17 Answer:

1.2.18 The best model that was found based on the validation set is:

[31]:
```
max_validation_cnn=validation_performances_cnn.
 ↪index(max(validation_performances_cnn))
print (cnn_model_names[max_validation_cnn])
print (cnn_models[max_validation_cnn].summary())

print("Emotion Classification Accuracy on the Validation set for the cnn model:␣
 ↪{} ".format(validation_performances_cnn[max_validation_cnn]))
```

```
cnn_model_1
Model: "sequential_5"

_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 conv2d (Conv2D)             (None, 46, 46, 32)        320

 conv2d_1 (Conv2D)           (None, 44, 44, 32)        9248

 max_pooling2d (MaxPooling2D  (None, 22, 22, 32)       0
 )

 conv2d_2 (Conv2D)           (None, 20, 20, 64)        18496

 conv2d_3 (Conv2D)           (None, 18, 18, 64)        36928

 max_pooling2d_1 (MaxPooling  (None, 9, 9, 64)         0
 2D)

 flatten (Flatten)           (None, 5184)              0

 dense_5 (Dense)             (None, 512)               2654720

 dense_6 (Dense)             (None, 7)                 3591

=================================================================
Total params: 2,723,303
Trainable params: 2,723,303
Non-trainable params: 0
_________________________________________________________________
None
Emotion Classification Accuracy on the Validation set for the cnn model:
0.5736973881721497
```

1.2.19 The emotion classification accuracy of the model on the testing dataset is:

[32]:
```
test_images_3d = flatten_test_images.reshape(len(flatten_test_images),48,48,1)

test_performance_cnn = cnn_models[max_validation_cnn].evaluate(test_images_3d,␣
↪to_categorical(test_emotions))
print("Emotion Classification Accuracy on the Testing set for the CNN: {0}".
↪format(test_performance_cnn[1]))
print ("  ")
print("And Emotion Classification Accuracy on the Testing set for the FNN: {0}".
↪format(test_performance[1]))
```

```
113/113 [==============================] - 1s 8ms/step - loss: 2.7430 -
accuracy: 0.5812
Emotion Classification Accuracy on the Testing set for the CNN:
0.5812203884124756

And Emotion Classification Accuracy on the Testing set for the FNN:
0.47283366322517395
```

1.2.20 We can see that the Emotion Classification Accuracy on the Testing set for the CNN (58.12%) is better than that of the FNN (47.28%).

1.2.21 (e) (1 point) Bayesian optimization for hyper-parameter tuning: Instead of performing grid or random search to tune the hyper-parameters of the CNN, we can also try a model-based method for finding the optimal hyper-parameters through Bayesian optimization. This method performs a more intelligent search on the hyper-parameter space in order to estimate the best set of hyper-parameters for the data. Use publicly available libraries (e.g., hyperopt in Python) to perform a Bayesian optimization on the hyper-parameter space using the validation set. Report the emotion classification accuracy on the testing set.

[19]:
```
!pip install hyperopt
```

```
Requirement already satisfied: hyperopt in /usr/local/lib/python3.7/dist-
packages (0.1.2)
Requirement already satisfied: tqdm in /usr/local/lib/python3.7/dist-packages
(from hyperopt) (4.62.3)
Requirement already satisfied: six in /usr/local/lib/python3.7/dist-packages
(from hyperopt) (1.15.0)
Requirement already satisfied: networkx in /usr/local/lib/python3.7/dist-
packages (from hyperopt) (2.6.3)
Requirement already satisfied: numpy in /usr/local/lib/python3.7/dist-packages
(from hyperopt) (1.19.5)
Requirement already satisfied: scipy in /usr/local/lib/python3.7/dist-packages
(from hyperopt) (1.4.1)
Requirement already satisfied: future in /usr/local/lib/python3.7/dist-packages
(from hyperopt) (0.16.0)
```

```
Requirement already satisfied: pymongo in /usr/local/lib/python3.7/dist-packages
(from hyperopt) (3.12.1)
```

[20]:
```python
from hyperopt import hp, fmin, tpe, STATUS_OK, Trials
```

[21]:
```python
def optimize_cnn(hyperparameter):

  # Defining model using hyperparameters
  cnn_model = Sequential([Conv2D(32,␣
 ↪kernel_size=hyperparameter['conv_kernel_size'],␣
 ↪activation=hyperparameter['activation_fn'], input_shape=(48,48,1)),
             Conv2D(32, kernel_size=hyperparameter['conv_kernel_size'],␣
 ↪activation=hyperparameter['activation_fn']),
             MaxPooling2D(pool_size=(2,2)),␣
 ↪Dropout(hyperparameter['dropout_prob']),
             Conv2D(64, kernel_size=hyperparameter['conv_kernel_size'],␣
 ↪activation=hyperparameter['activation_fn']),
             Conv2D(128, kernel_size=hyperparameter['conv_kernel_size'],␣
 ↪activation=hyperparameter['activation_fn']),
             MaxPooling2D(pool_size=(2,2)),␣
 ↪Dropout(hyperparameter['dropout_prob']),
             Flatten(),
             Dense(512, hyperparameter['activation_fn']),
             Dense(len(emotions), activation='softmax'),])

  cnn_model.compile(optimizer=hyperparameter['optimizer'],␣
 ↪loss='categorical_crossentropy', metrics=['accuracy'],)


  train_X, train_y = train_images_3d, train_emotions
  valid_X, valid_y = validation_images_3d, validation_emotions

  _ = cnn_model.fit(train_X, to_categorical(train_y), epochs=10,␣
 ↪batch_size=256, verbose=0)
  # Evaluating accuracy on validation data
  performance = cnn_model.evaluate(valid_X, to_categorical(valid_y), verbose=0)

  print("Hyperparameters: ", hyperparameter, "Accuracy: ", performance[1])
  print("----------------------------------------------------")

  return({"status": STATUS_OK, "loss": -1*performance[1], "model":cnn_model})


# Defining 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']),
    #choice of activation function
    'activation_fn': hp.choice('activation', ['relu', 'sigmoid', 'elu']),
}

trials = Trials()

# Finding the best hyperparameters
best = fmin(
        optimize_cnn,
        space,
        algo=tpe.suggest,
        trials=trials,
        max_evals=15,
    )

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


test_model = trials.results[np.argmin([r['loss'] for r in trials.
 ↪results])]['model']

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

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

```
Hyperparameters:
{'activation_fn': 'sigmoid', 'conv_kernel_size': 5, 'dropout_prob':
0.15266477923626062, 'optimizer': 'sgd'}
Accuracy:
0.24937307834625244
----------------------------------------------------
Hyperparameters:
{'activation_fn': 'elu', 'conv_kernel_size': 3, 'dropout_prob':
0.31596639352914324, 'optimizer': 'Adam'}
Accuracy:
0.5539147257804871
----------------------------------------------------
Hyperparameters:
{'activation_fn': 'relu', 'conv_kernel_size': 1, 'dropout_prob':
0.1744496091134044, 'optimizer': 'Adam'}
Accuracy:
0.47088325023651123
```

```
----------------------------------------------------
Hyperparameters:
{'activation_fn': 'sigmoid', 'conv_kernel_size': 1, 'dropout_prob':
0.287162391630506, 'optimizer': 'sgd'}
Accuracy:
0.24937307834625244
----------------------------------------------------
Hyperparameters:
{'activation_fn': 'relu', 'conv_kernel_size': 5, 'dropout_prob':
0.2448089365657019, 'optimizer': 'Adam'}
Accuracy:
0.592644214630127
----------------------------------------------------
Hyperparameters:
{'activation_fn': 'sigmoid', 'conv_kernel_size': 1, 'dropout_prob':
0.29375151885611395, 'optimizer': 'Adam'}
Accuracy:
0.24937307834625244
----------------------------------------------------
Hyperparameters:
{'activation_fn': 'elu', 'conv_kernel_size': 3, 'dropout_prob':
0.12498432433670034, 'optimizer': 'sgd'}
Accuracy:
0.3736416697502136
----------------------------------------------------
Hyperparameters:
{'activation_fn': 'elu', 'conv_kernel_size': 5, 'dropout_prob':
0.316955992072036, 'optimizer': 'sgd'}
Accuracy:
0.37977153062820435
----------------------------------------------------
Hyperparameters:
{'activation_fn': 'sigmoid', 'conv_kernel_size': 3, 'dropout_prob':
0.1439456589291522, 'optimizer': 'sgd'}
Accuracy:
0.1819448322057724
----------------------------------------------------
Hyperparameters:
{'activation_fn': 'sigmoid', 'conv_kernel_size': 1, 'dropout_prob':
0.14360078356291128, 'optimizer': 'Adam'}
Accuracy:
0.24937307834625244
----------------------------------------------------
Hyperparameters:
{'activation_fn': 'elu', 'conv_kernel_size': 1, 'dropout_prob':
0.14857276563606964, 'optimizer': 'sgd'}
Accuracy:
0.38395094871520996
```

```
----------------------------------------------------
Hyperparameters:
{'activation_fn': 'elu', 'conv_kernel_size': 1, 'dropout_prob':
0.21999128824946373, 'optimizer': 'Adam'}
Accuracy:
0.37698522210121155
----------------------------------------------------
Hyperparameters:
{'activation_fn': 'relu', 'conv_kernel_size': 5, 'dropout_prob':
0.27824443302614543, 'optimizer': 'Adam'}
Accuracy:
0.585121214389801
----------------------------------------------------
Hyperparameters:
{'activation_fn': 'relu', 'conv_kernel_size': 1, 'dropout_prob':
0.1268864685218872, 'optimizer': 'Adam'}
Accuracy:
0.4505433142185211
----------------------------------------------------
Hyperparameters:
{'activation_fn': 'elu', 'conv_kernel_size': 3, 'dropout_prob':
0.13194258629013292, 'optimizer': 'Adam'}
Accuracy:
0.5215937495231628
----------------------------------------------------
100%|     | 15/15 [21:24<00:00, 85.63s/it, best loss: -0.592644214630127]
==================================
Best Hyperparameters {'activation': 0, 'conv_kernel_size': 2, 'dropout_prob':
0.2448089365657019, 'optimizer': 0}
113/113 [==============================] - 1s 7ms/step - loss: 1.0938 -
accuracy: 0.5940
==================================
Test Accuracy:  0.5940373539924622
```

1.2.22 The best hypermeters are: {'activation': 'relu', 'conv_kernel_size': 5, 'dropout_prob': 0.2448089365657019, 'optimizer': 'Adam'}

1.2.23 The emotion classification accuracy on the testing set with the best hyperparameters is as follows:

[22]:
```python
performance = test_model.evaluate(test_images_3d, to_categorical(test_emotions))

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

```
113/113 [==============================] - 1s 8ms/step - loss: 1.0938 -
accuracy: 0.5940
==================================
Test Accuracy:  0.5940373539924622
```

1.2.24 (f) (Bonus - 1 point) Fine-tuning: Use a pre-trained CNN (e.g., the pre-trained example of the MNIST dataset that we saw in class, or any other available pre-trained CNN) and fine-tune it on the FER data. Please experiment with different fine-tuning hyper-parameters (e.g., layers to fine-tune, regularization during fine-tuning) on the validation set. Report the classification accuracy for all hyper-parameter combinations on the validation set. Also report the classification accuracy with the best hyper-parameter combination on the testing set.

[23]:
```
from tensorflow.keras.applications import MobileNetV2
from tensorflow.keras.applications.inception_v3 import InceptionV3
from tensorflow.keras.applications.efficientnet import EfficientNetB0
from tensorflow.keras.applications.resnet50 import ResNet50

from tensorflow.keras.applications.inception_resnet_v2 import InceptionResNetV2
from tensorflow.python.keras.layers import Dense, Flatten,␣
↪GlobalAveragePooling2D, Activation, Flatten, Dropout, BatchNormalization
from keras.applications.inception_resnet_v2 import preprocess_input
from tensorflow.keras.layers import RandomFlip, RandomRotation
from tensorflow.keras import Input, Model
from tensorflow.image import grayscale_to_rgb
from tensorflow import convert_to_tensor


model_ft_1 = Sequential()
model_ft_1.add(ResNet50(input_shape=(48,48,3), include_top=False,␣
↪pooling='avg', weights="imagenet"))
# model.trainable=False
model_ft_1.add(Dense(512))
model_ft_1.add(Activation('relu'))
model_ft_1.add(Dense(1024))
model_ft_1.add(Activation('relu'))
model_ft_1.add(Dense(512))
model_ft_1.add(Activation('relu'))
model_ft_1.add(Dropout(0.3))
model_ft_1.add(Dense(len(emotions), activation='softmax'))
model_ft_1.layers[0].trainable = False
model_ft_1.compile(optimizer='adam', loss='categorical_crossentropy',␣
↪metrics=['accuracy'])



model_ft_2 = Sequential()
model_ft_2.add( MobileNetV2(input_shape=(48,48,3), include_top=False,␣
↪pooling='avg', weights="imagenet"))
# model.trainable=False
model_ft_2.add(Dense(512))
```

```
model_ft_2.add(Activation('relu'))
model_ft_2.add(Dense(1024))
model_ft_2.add(Activation('relu'))
model_ft_2.add(Dense(512))
model_ft_2.add(Activation('relu'))
model_ft_2.add(Dropout(0.4))
model_ft_2.add(Dense(len(emotions), activation='softmax'))
model_ft_2.layers[0].trainable = False
model_ft_2.compile(optimizer='adam', loss='categorical_crossentropy',␣
 ↪metrics=['accuracy'])




model_ft_3 = Sequential()
model_ft_3 .add( MobileNetV2(input_shape=(48,48,3), include_top=False,␣
 ↪pooling='avg', weights="imagenet"))
# model.trainable=False
model_ft_3 .add(Dense(512, kernel_regularizer=regularizers.l2(0.01)))
model_ft_3 .add(Activation('elu'))
model_ft_3 .add(Dense(1024, kernel_regularizer=regularizers.l2(0.01)))
model_ft_3 .add(Activation('elu'))
model_ft_3 .add(Dense(512, kernel_regularizer=regularizers.l2(0.01)))
model_ft_3 .add(Activation('elu'))
model_ft_3 .add(Dropout(0.3))
model_ft_3 .add(Dense(len(emotions), activation='softmax'))
model_ft_3 .layers[0].trainable = False
model_ft_3 .compile(optimizer='adam', loss='categorical_crossentropy',␣
 ↪metrics=['accuracy'])




train_images_3d_3=grayscale_to_rgb(convert_to_tensor(train_images_3d))

history_ft_1 = model_ft_1.fit(train_images_3d_3,␣
 ↪to_categorical(train_emotions), epochs=10, batch_size=256, verbose=1)
history_ft_2 = model_ft_2.fit(train_images_3d_3,␣
 ↪to_categorical(train_emotions), epochs=15, batch_size=256, verbose=1)
history_ft_3 = model_ft_3.fit(train_images_3d_3,␣
 ↪to_categorical(train_emotions), epochs=15, batch_size=256, verbose=1)
```

```
Downloading data from https://storage.googleapis.com/tensorflow/keras-
applications/resnet/resnet50_weights_tf_dim_ordering_tf_kernels_notop.h5
94773248/94765736 [==============================] - 1s 0us/step
94781440/94765736 [==============================] - 1s 0us/step
WARNING:tensorflow:`input_shape` is undefined or non-square, or `rows` is not in
```

```
[96, 128, 160, 192, 224]. Weights for input shape (224, 224) will be loaded as
the default.
Downloading data from https://storage.googleapis.com/tensorflow/keras-applicatio
ns/mobilenet_v2/mobilenet_v2_weights_tf_dim_ordering_tf_kernels_1.0_224_no_top.h
5
9412608/9406464 [==============================] - 0s 0us/step
9420800/9406464 [==============================] - 0s 0us/step
WARNING:tensorflow:`input_shape` is undefined or non-square, or `rows` is not in
[96, 128, 160, 192, 224]. Weights for input shape (224, 224) will be loaded as
the default.
Epoch 1/10
113/113 [==============================] - 19s 123ms/step - loss: 1.8139 -
accuracy: 0.2447
Epoch 2/10
113/113 [==============================] - 13s 119ms/step - loss: 1.7682 -
accuracy: 0.2650
Epoch 3/10
113/113 [==============================] - 13s 119ms/step - loss: 1.7483 -
accuracy: 0.2810
Epoch 4/10
113/113 [==============================] - 13s 119ms/step - loss: 1.7168 -
accuracy: 0.3006
Epoch 5/10
113/113 [==============================] - 13s 119ms/step - loss: 1.7078 -
accuracy: 0.3065
Epoch 6/10
113/113 [==============================] - 14s 120ms/step - loss: 1.6895 -
accuracy: 0.3203
Epoch 7/10
113/113 [==============================] - 14s 120ms/step - loss: 1.6880 -
accuracy: 0.3198
Epoch 8/10
113/113 [==============================] - 13s 119ms/step - loss: 1.6691 -
accuracy: 0.3344
Epoch 9/10
113/113 [==============================] - 14s 120ms/step - loss: 1.6706 -
accuracy: 0.3336
Epoch 10/10
113/113 [==============================] - 14s 120ms/step - loss: 1.6562 -
accuracy: 0.3427
Epoch 1/15
113/113 [==============================] - 12s 72ms/step - loss: 1.6875 -
accuracy: 0.3315
Epoch 2/15
113/113 [==============================] - 8s 70ms/step - loss: 1.5157 -
accuracy: 0.4143
Epoch 3/15
113/113 [==============================] - 8s 69ms/step - loss: 1.3848 -
```

```
accuracy: 0.4745
Epoch 4/15
113/113 [==============================] - 8s 69ms/step - loss: 1.1953 -
accuracy: 0.5571
Epoch 5/15
113/113 [==============================] - 8s 70ms/step - loss: 0.9751 -
accuracy: 0.6465
Epoch 6/15
113/113 [==============================] - 8s 70ms/step - loss: 0.7550 -
accuracy: 0.7327
Epoch 7/15
113/113 [==============================] - 8s 69ms/step - loss: 0.5858 -
accuracy: 0.7967
Epoch 8/15
113/113 [==============================] - 8s 69ms/step - loss: 0.4517 -
accuracy: 0.8442
Epoch 9/15
113/113 [==============================] - 8s 69ms/step - loss: 0.3559 -
accuracy: 0.8786
Epoch 10/15
113/113 [==============================] - 8s 69ms/step - loss: 0.2589 -
accuracy: 0.9131
Epoch 11/15
113/113 [==============================] - 8s 69ms/step - loss: 0.2060 -
accuracy: 0.9319
Epoch 12/15
113/113 [==============================] - 8s 70ms/step - loss: 0.1797 -
accuracy: 0.9402
Epoch 13/15
113/113 [==============================] - 8s 69ms/step - loss: 0.1545 -
accuracy: 0.9500
Epoch 14/15
113/113 [==============================] - 8s 69ms/step - loss: 0.1486 -
accuracy: 0.9513
Epoch 15/15
113/113 [==============================] - 8s 70ms/step - loss: 0.1208 -
accuracy: 0.9588
Epoch 1/15
113/113 [==============================] - 12s 72ms/step - loss: 1.8576 -
accuracy: 0.3234
Epoch 2/15
113/113 [==============================] - 8s 72ms/step - loss: 1.5784 -
accuracy: 0.3922
Epoch 3/15
113/113 [==============================] - 8s 72ms/step - loss: 1.4853 -
accuracy: 0.4257
Epoch 4/15
113/113 [==============================] - 8s 72ms/step - loss: 1.4071 -
```

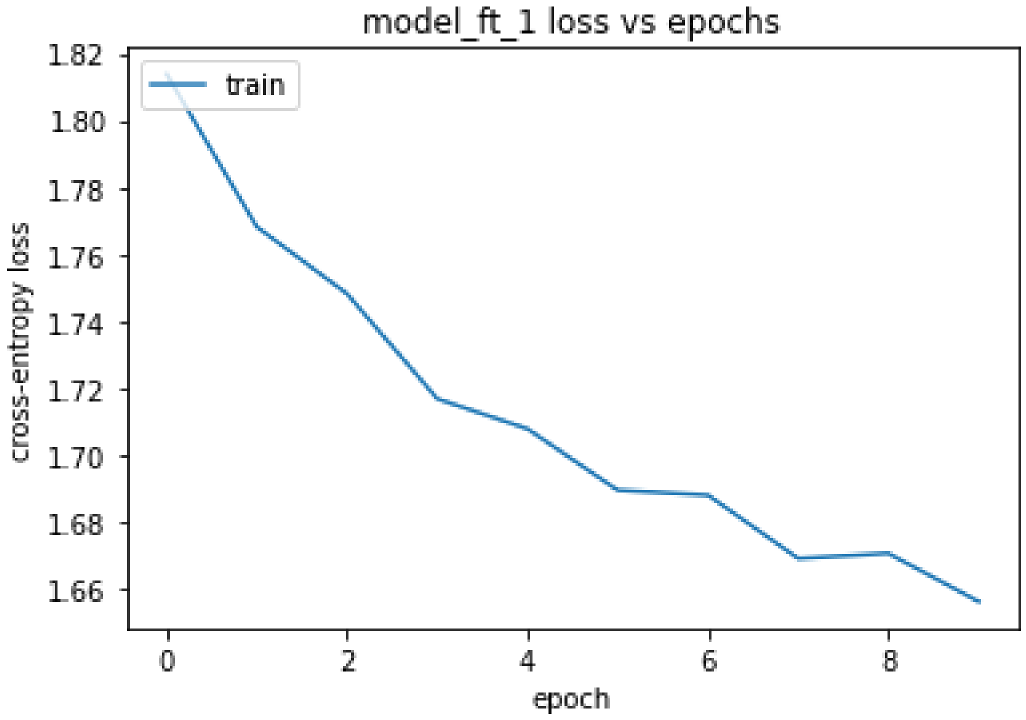
```
accuracy: 0.4622
Epoch 5/15
113/113 [==============================] - 8s 72ms/step - loss: 1.3213 -
accuracy: 0.4960
Epoch 6/15
113/113 [==============================] - 8s 72ms/step - loss: 1.2378 -
accuracy: 0.5301
Epoch 7/15
113/113 [==============================] - 8s 72ms/step - loss: 1.1497 -
accuracy: 0.5668
Epoch 8/15
113/113 [==============================] - 8s 73ms/step - loss: 1.0500 -
accuracy: 0.6091
Epoch 9/15
113/113 [==============================] - 8s 72ms/step - loss: 0.9576 -
accuracy: 0.6406
Epoch 10/15
113/113 [==============================] - 8s 72ms/step - loss: 0.8568 -
accuracy: 0.6835
Epoch 11/15
113/113 [==============================] - 8s 73ms/step - loss: 0.7484 -
accuracy: 0.7248
Epoch 12/15
113/113 [==============================] - 8s 72ms/step - loss: 0.6589 -
accuracy: 0.7587
Epoch 13/15
113/113 [==============================] - 8s 72ms/step - loss: 0.5760 -
accuracy: 0.7881
Epoch 14/15
113/113 [==============================] - 8s 72ms/step - loss: 0.4831 -
accuracy: 0.8257
Epoch 15/15
113/113 [==============================] - 8s 71ms/step - loss: 0.4291 -
accuracy: 0.8449
```

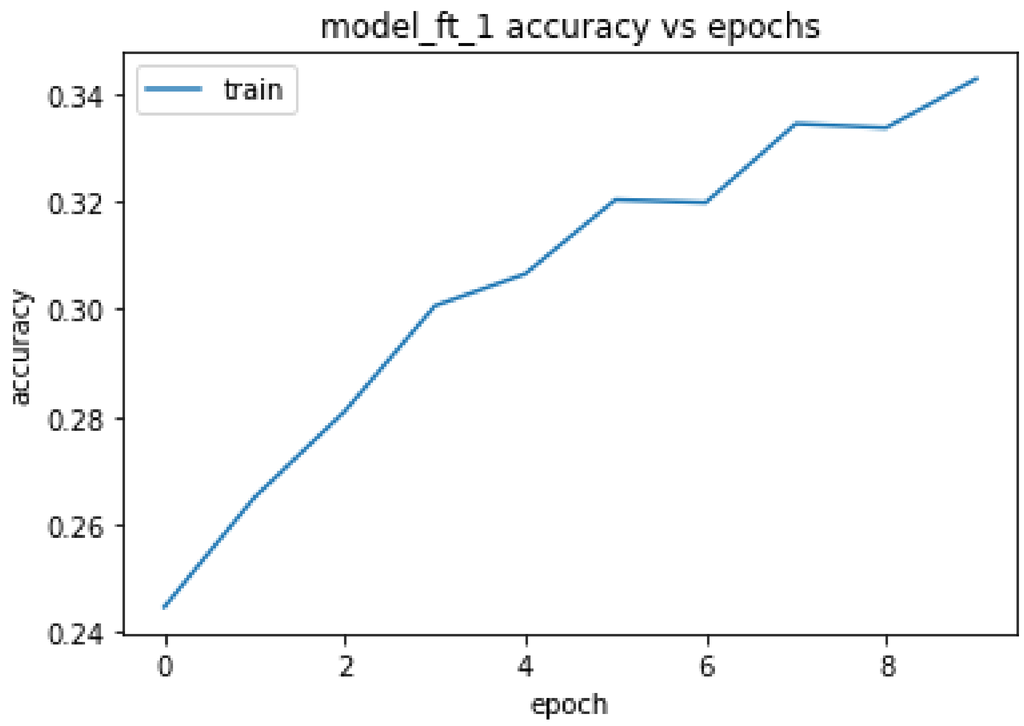
[24]:
```
validation_images_3d_3=grayscale_to_rgb(convert_to_tensor(validation_images_3d))

# performance = model_ft_3.evaluate(validation_images_3d_3,␣
↪to_categorical(validation_emotions))

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


validation_performances_ft=[]
ft_models=[model_ft_1,model_ft_2,model_ft_3]
ft_model_names=['model_ft_1','model_ft_2','model_ft_3']
```

```
ft_histories=[history_ft_1,history_ft_2,history_ft_3]
for i in range(len(ft_models)):
  print (" ")
  print ("Required details for {}".format(ft_model_names[i]))
  print (" ")
  performance1_ft = ft_models[i].evaluate(train_images_3d_3,␣
 ↪to_categorical(train_emotions))
  print("Emotion Classification Accuracy on the Training set: {0}".
 ↪format(performance1_ft[1]))
  print (" ")
  performance2_ft = ft_models[i].evaluate(validation_images_3d_3,␣
 ↪to_categorical(validation_emotions))
  validation_performances_ft.append(performance2_ft[1])
  print("Emotion Classification Accuracy on the Validation set: {0}".
 ↪format(performance2_ft[1]))
  print (" ")
  print ("Parameters for the model:")
  print (" ")
  print (ft_models[i].summary())


  print (" ")
  print('Number of Epochs used to train the model: ', len(ft_histories[i].
 ↪history['loss']))




  print(" ")
  # print(history.history.keys())
  # summarize history for loss
  plt.plot(ft_histories[i].history['loss'])
  plt.title('{} loss vs epochs'.format(ft_model_names[i]))
  plt.ylabel('cross-entropy loss')
  plt.xlabel('epoch')
  plt.legend(['train'], loc='upper left')
  plt.show()
  # summarize history for accuracy
  plt.plot(ft_histories[i].history['accuracy'])
  plt.title('{} accuracy vs epochs'.format(ft_model_names[i]))
  plt.ylabel('accuracy')
  plt.xlabel('epoch')
  plt.legend(['train'], loc='upper left')
  plt.show()

  print (" ")
  print (" ")
```

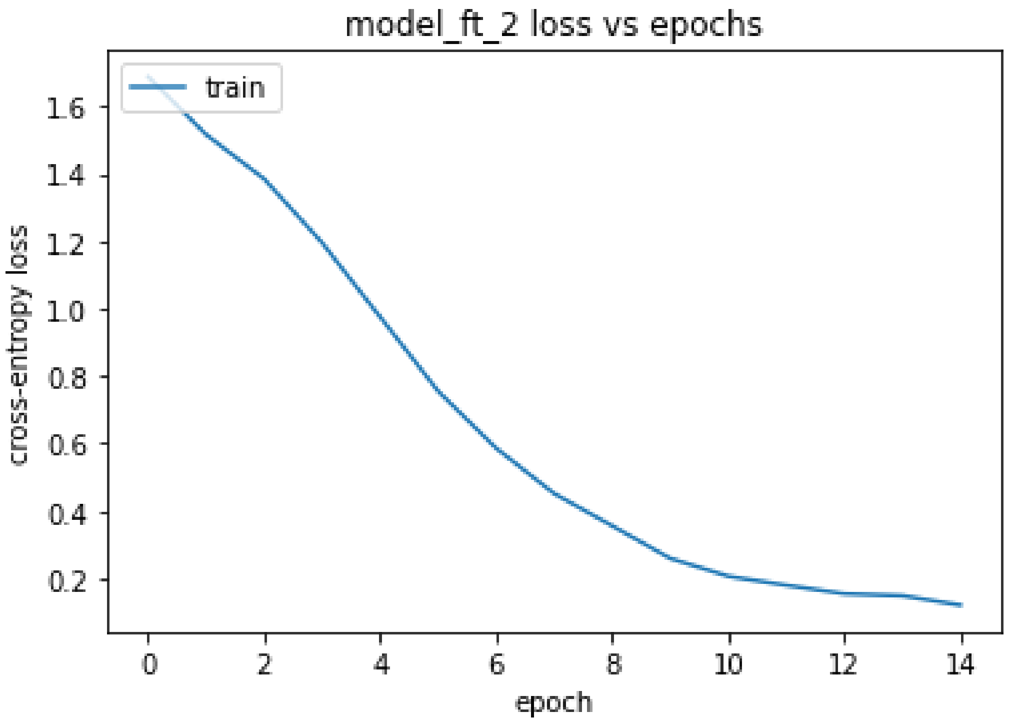
```
Required details for model_ft_1

898/898 [==============================] - 33s 35ms/step - loss: 1.6846 -
accuracy: 0.3244
Emotion Classification Accuracy on the Training set: 0.32442787289619446

113/113 [==============================] - 4s 35ms/step - loss: 1.7151 -
accuracy: 0.3104
Emotion Classification Accuracy on the Validation set: 0.3103928565979004

Parameters for the model:

Model: "sequential_23"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 resnet50 (Functional)       (None, 2048)              23587712

 module_wrapper (ModuleWrapp  (None, 512)              1049088
 er)

 module_wrapper_1 (ModuleWra  (None, 512)              0
 pper)

 module_wrapper_2 (ModuleWra  (None, 1024)             525312
 pper)

 module_wrapper_3 (ModuleWra  (None, 1024)             0
 pper)

 module_wrapper_4 (ModuleWra  (None, 512)              524800
 pper)

 module_wrapper_5 (ModuleWra  (None, 512)              0
 pper)

 module_wrapper_6 (ModuleWra  (None, 512)              0
 pper)

 module_wrapper_7 (ModuleWra  (None, 7)                3591
 pper)

=================================================================
Total params: 25,690,503
Trainable params: 2,102,791
Non-trainable params: 23,587,712
_________________________________________________________________
```

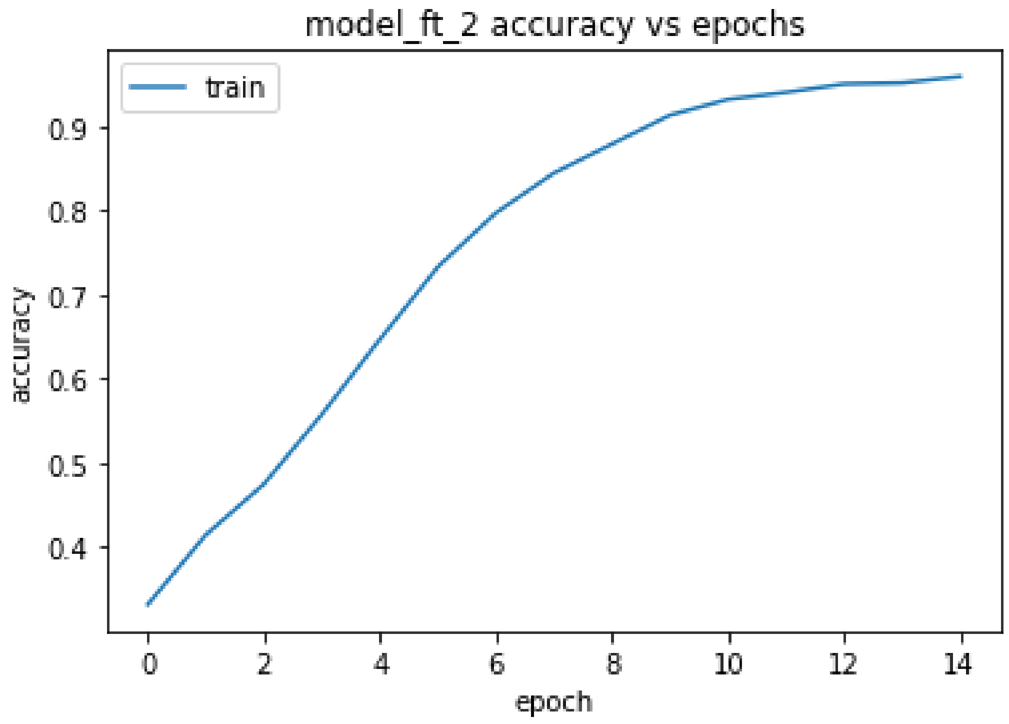
```
None

Number of Epochs used to train the model:  10
```





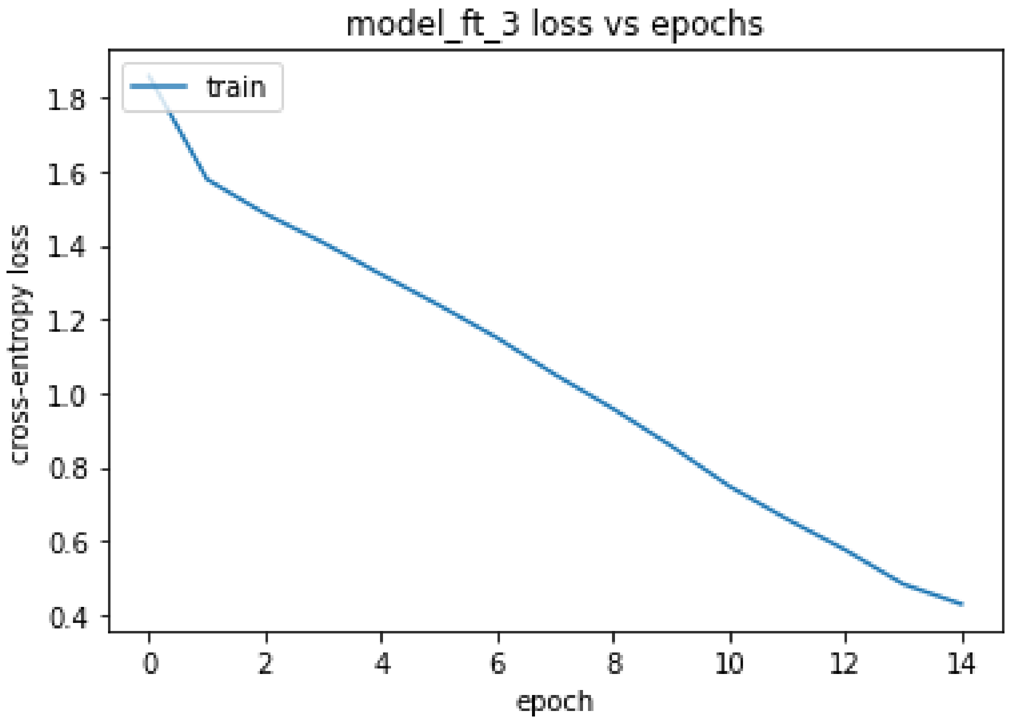
```
Required details for model_ft_2

898/898 [==============================] - 20s 21ms/step - loss: 0.0624 -
accuracy: 0.9808
Emotion Classification Accuracy on the Training set: 0.9807725548744202

113/113 [==============================] - 2s 21ms/step - loss: 3.8308 -
accuracy: 0.4230
Emotion Classification Accuracy on the Validation set: 0.42295902967453003

Parameters for the model:

Model: "sequential_24"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 mobilenetv2_1.00_224 (Funct  (None, 1280)             2257984
 ional)

 module_wrapper_8 (ModuleWra  (None, 512)              655872
 pper)
 module_wrapper_9 (ModuleWra  (None, 512)              0
 pper)

 module_wrapper_10 (ModuleWr  (None, 1024)             525312
 apper)

 module_wrapper_11 (ModuleWr  (None, 1024)             0
 apper)

 module_wrapper_12 (ModuleWr  (None, 512)              524800
 apper)

 module_wrapper_13 (ModuleWr  (None, 512)              0
 apper)

 module_wrapper_14 (ModuleWr  (None, 512)              0
 apper)

 module_wrapper_15 (ModuleWr  (None, 7)                3591
 apper)

=================================================================
Total params: 3,967,559
Trainable params: 1,709,575
Non-trainable params: 2,257,984
_________________________________________________________________
None

Number of Epochs used to train the model:  15
```

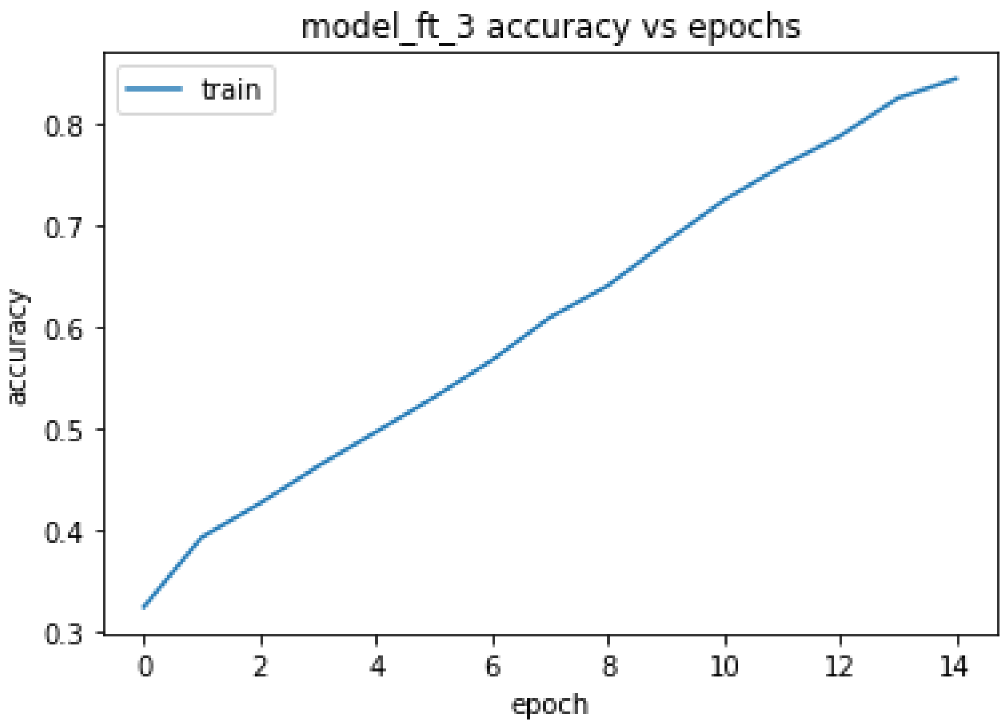

model_ft_2 loss vs epochs
train
cross-entropy loss
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0
2
4
6
8
10
12
14
epoch


model_ft_2 accuracy vs epochs
train
accuracy
0.9
0.8
0.7
0.6
0.5
0.4
0
2
4
6
8
10
12
14
epoch

```
Required details for model_ft_3

898/898 [==============================] - 19s 20ms/step - loss: 0.3500 -
accuracy: 0.8713
Emotion Classification Accuracy on the Training set: 0.8713295459747314

113/113 [==============================] - 2s 19ms/step - loss: 2.8958 -
accuracy: 0.4322
Emotion Classification Accuracy on the Validation set: 0.4321537911891937

Parameters for the model:

Model: "sequential_25"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 mobilenetv2_1.00_224 (Funct  (None, 1280)             2257984
 ional)

 module_wrapper_16 (ModuleWr  (None, 512)              655872
 apper)

 module_wrapper_17 (ModuleWr  (None, 512)              0
 apper)

 module_wrapper_18 (ModuleWr  (None, 1024)             525312
 apper)

 module_wrapper_19 (ModuleWr  (None, 1024)             0
 apper)

 module_wrapper_20 (ModuleWr  (None, 512)              524800
 apper)

 module_wrapper_21 (ModuleWr  (None, 512)              0
 apper)

 module_wrapper_22 (ModuleWr  (None, 512)              0
 apper)

 module_wrapper_23 (ModuleWr  (None, 7)                3591
 apper)

=================================================================
Total params: 3,967,559
```

```
Trainable params: 1,709,575
Non-trainable params: 2,257,984
_________________________________________________________________
None

Number of Epochs used to train the model:  15
```





1.2.25 Answer:

Three different fine-tuned models have been trained on the training dataset and evaluated on the validation dataset. The required details are shown above. The values in a tabular form is shown below:

Model name	Accuracy on Train dataset (%)	Accuracy on Validation dataset (%)	Total Trainable Parameters Count
model_ft_1	32.44	31.04	2,102,791
model_ft_2	98.08	42.30	1,709,575
model_ft_3	87.13	43.22	1,709,575

1.2.26 The best fine-tuned model that was found based on the validation set is:

[42]:
```python
max_validation_ft=validation_performances_ft.
 ↪index(max(validation_performances_ft))
print (ft_model_names[max_validation_ft])
print (ft_models[max_validation_ft].summary())
```

```
print("Emotion Classification Accuracy on the Validation set for the fine-tuned␣
↪model: {} ".format(validation_performances_ft[max_validation_ft]))
```

```
model_ft_3
Model: "sequential_25"
_________________________________________________________________
 Layer (type)                Output Shape              Param #
=================================================================
 mobilenetv2_1.00_224 (Funct  (None, 1280)             2257984
 ional)

 module_wrapper_16 (ModuleWr  (None, 512)              655872
 apper)

 module_wrapper_17 (ModuleWr  (None, 512)              0
 apper)

 module_wrapper_18 (ModuleWr  (None, 1024)             525312
 apper)

 module_wrapper_19 (ModuleWr  (None, 1024)             0
 apper)

 module_wrapper_20 (ModuleWr  (None, 512)              524800
 apper)

 module_wrapper_21 (ModuleWr  (None, 512)              0
 apper)

 module_wrapper_22 (ModuleWr  (None, 512)              0
 apper)

 module_wrapper_23 (ModuleWr  (None, 7)                3591
 apper)

=================================================================
Total params: 3,967,559
Trainable params: 1,709,575
Non-trainable params: 2,257,984
_________________________________________________________________
None
Emotion Classification Accuracy on the Validation set for the fine-tuned model:
0.4321537911891937
```

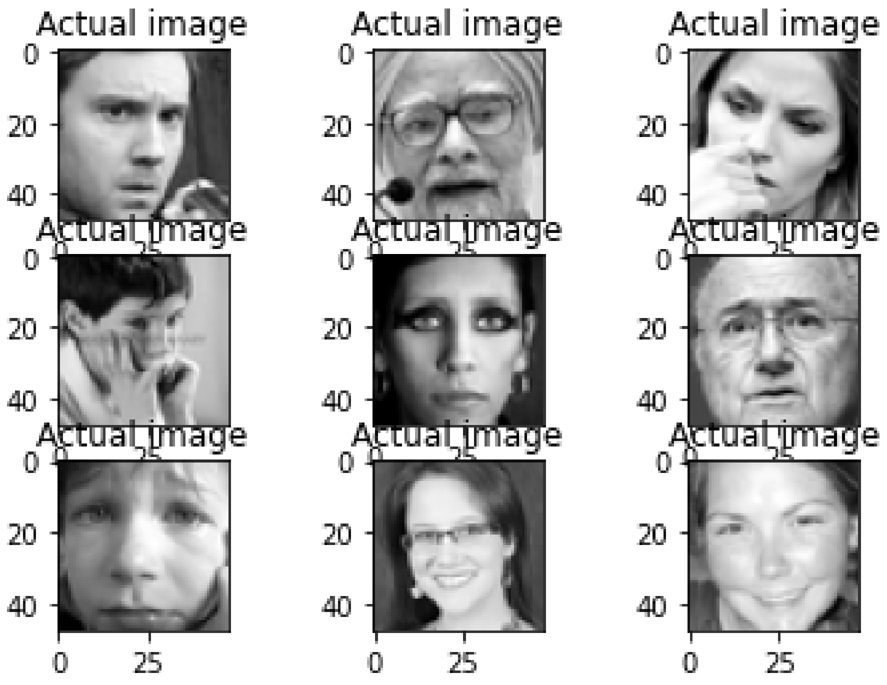
1.2.27 The emotion classification accuracy of the best fine-tuned model (created using mobilenetv2) on the testing dataset is:

[43]:
```
test_images_3d_3=grayscale_to_rgb(convert_to_tensor(test_images_3d))

test_performance_ft= ft_models[max_validation_ft].evaluate(test_images_3d_3,␣
 ↪to_categorical(test_emotions))
print("Emotion Classification Accuracy on the Testing set for the fine-tuned␣
 ↪model: {0}".format(test_performance_ft[1]))
```

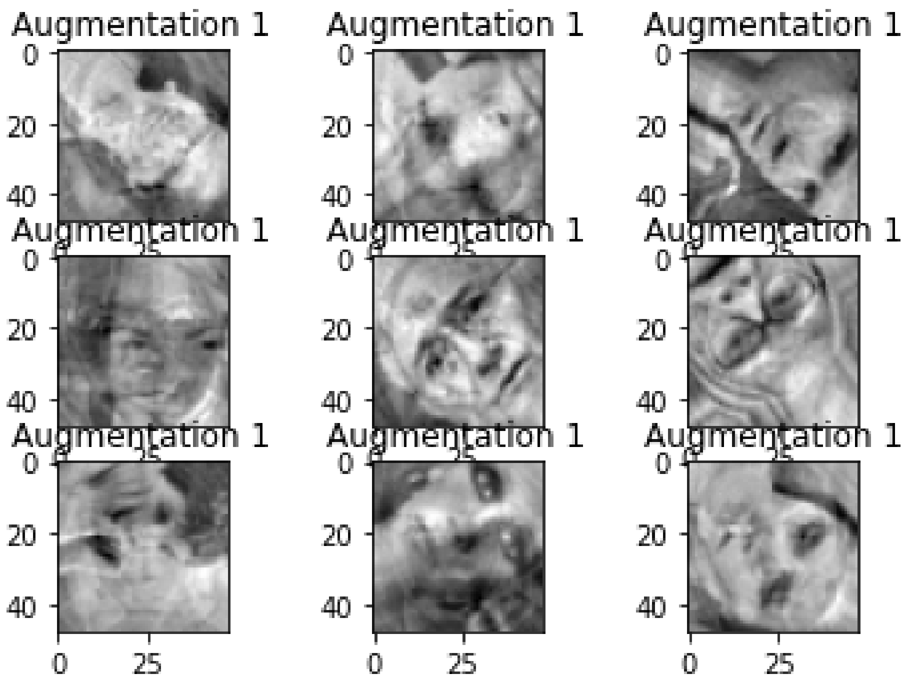
```
113/113 [==============================] - 2s 20ms/step - loss: 2.8454 -
accuracy: 0.4235
Emotion Classification Accuracy on the Testing set for the fine-tuned model:
0.42351630330085754
```

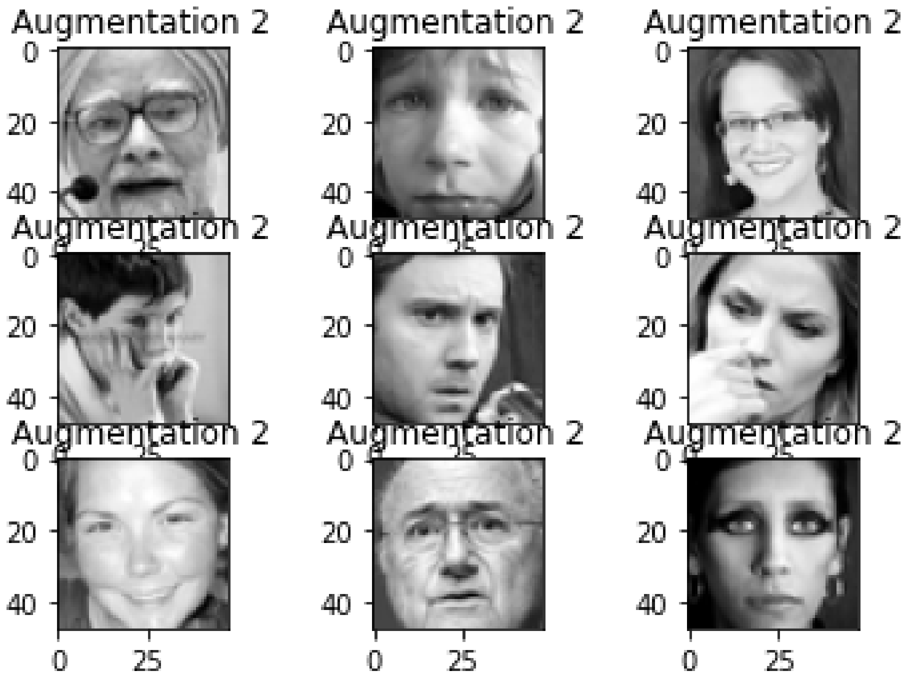
1.2.28 (g) (Bonus - 1 point) Data augmentation: Data augmentation is a way to increase the size of our dataset and reduce overfitting, especially when we use complicated models with manyparameters to learn. Using any available toolbox or your own code, implement some of these techniques and augment the original FER data.

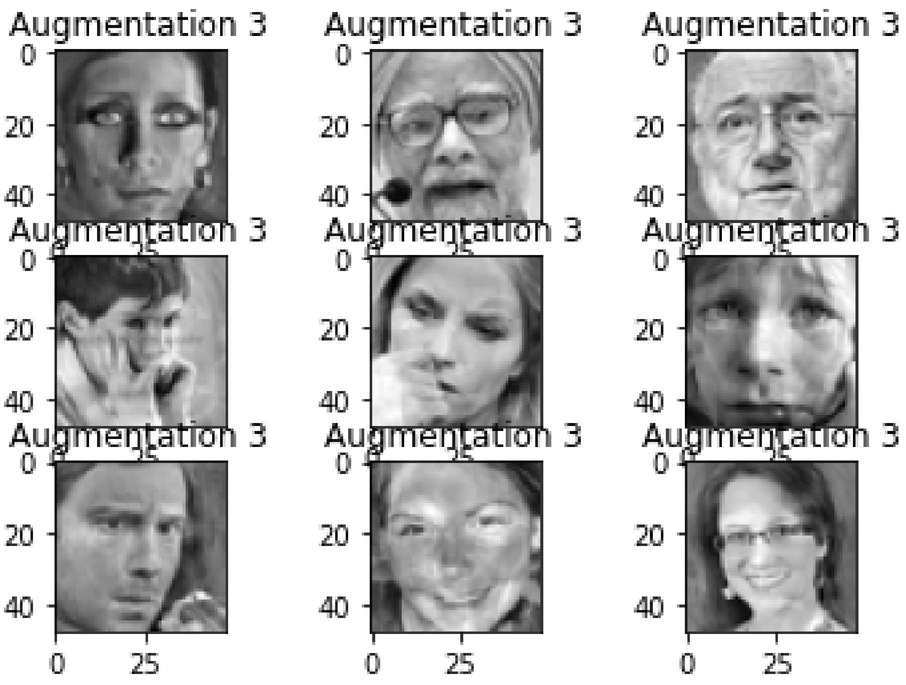
[41]:
```
from keras.preprocessing.image import ImageDataGenerator

for i in range(9):
  plt.subplot(330 + 1 + i)
  plt.title('Actual image')
  plt.imshow(train_images_3d[i].reshape(48, 48), cmap=plt.get_cmap('gray'))
plt.show()




shift=0.2
datagen1 = ImageDataGenerator(featurewise_center=True,␣
 ↪featurewise_std_normalization=True, zca_whitening=True, rotation_range=90,␣
 ↪width_shift_range=0.2, height_shift_range=0.2, horizontal_flip=True,␣
 ↪vertical_flip=True)
datagen2 = ImageDataGenerator(featurewise_center=True,␣
 ↪featurewise_std_normalization=True)
datagen3 = ImageDataGenerator(zca_whitening=True)
datagen4 = ImageDataGenerator(rotation_range=90)
datagen5 = ImageDataGenerator(width_shift_range=shift, height_shift_range=shift)


datagens=[datagen1, datagen2,datagen3, datagen4, datagen5]
labels=["Augmentation 1", "Augmentation 2", "Augmentation 3","Augmentation 4",␣
 ↪"Augmentation 5"]
for ij,datagen in enumerate(datagens):
    datagen.fit(train_images_3d[:9])
    for X_batch, y_batch in datagen.flow(train_images_3d[:9], train_emotions[:
↪9], batch_size=9):
        for i in range(0, 9):
            plt.subplot(330 + 1 + i)
            plt.title(labels[ij])
            plt.imshow(X_batch[i].reshape(48, 48), cmap=plt.get_cmap('gray'))
        plt.show()
        break
```

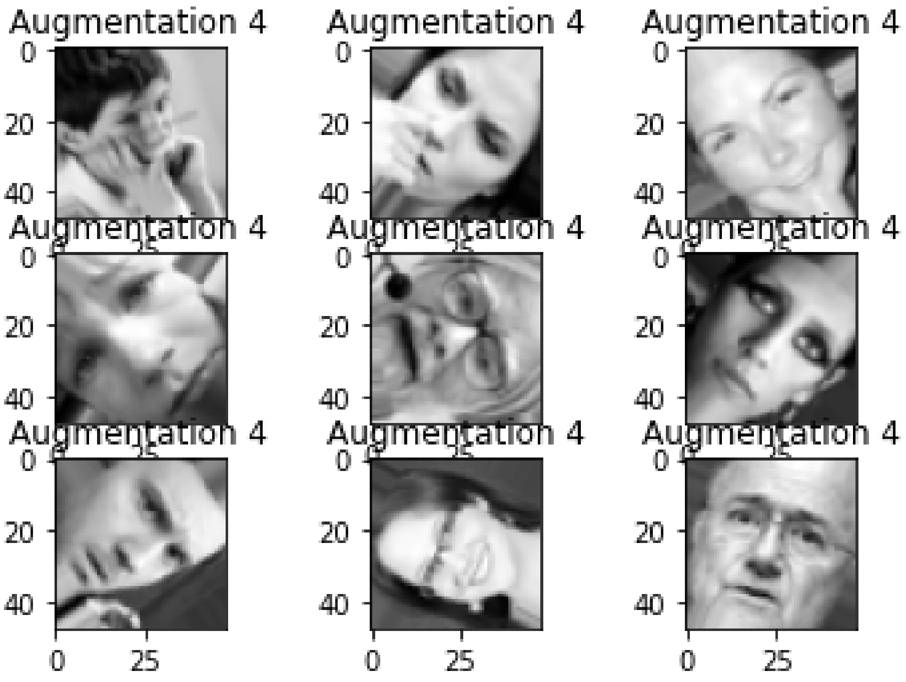


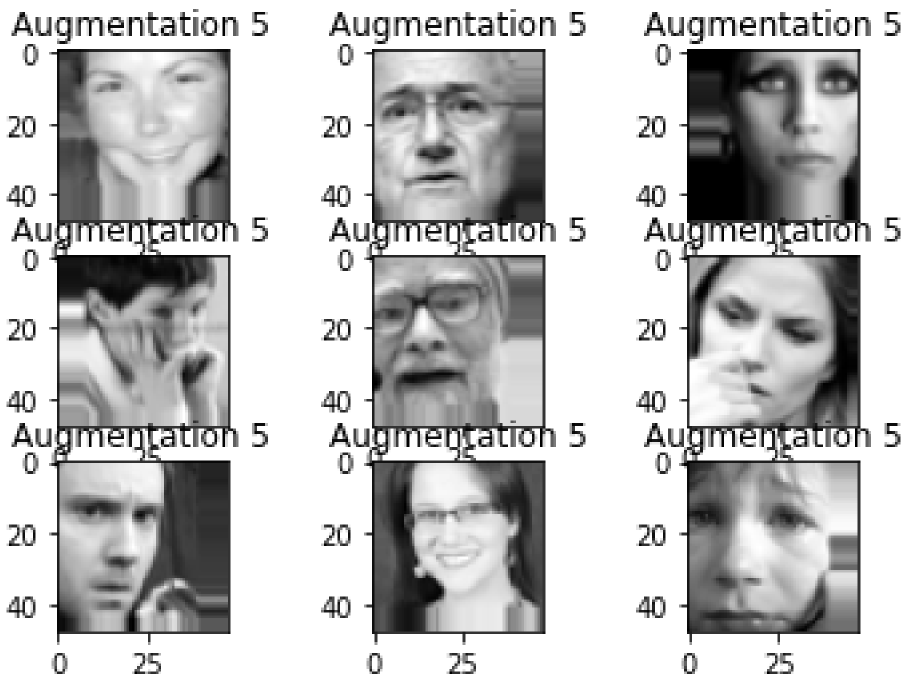
```
/usr/local/lib/python3.7/dist-
packages/keras_preprocessing/image/image_data_generator.py:342: UserWarning:
This ImageDataGenerator specifies `zca_whitening` which overrides setting
of`featurewise_std_normalization`.
  warnings.warn('This ImageDataGenerator specifies '
/usr/local/lib/python3.7/dist-
packages/keras_preprocessing/image/image_data_generator.py:337: UserWarning:
This ImageDataGenerator specifies `zca_whitening`, which overrides setting of
`featurewise_center`.
  warnings.warn('This ImageDataGenerator specifies '
```


Augmentation 1
0
20
40
0
25


Augmentation 2
0
20
40
0
25


Augmentation 3
0
20
40
0
25


Augmentation 4
0
20
40
0
25



Answer: Some outputs of the following data augmentation techniques are shown above:

1. datagen1 = ImageDataGenerator(featurewise_center=True, featurewise_std_normalization=True, zca_whitening=True, rotation_range=90, width_shift_range=0.2, height_shift_range=0.2, horizontal_flip=True, vertical_flip=True)
2. datagen2 = ImageDataGenerator(featurewise_center=True, featurewise_std_normalization=True)
3. datagen3 = ImageDataGenerator(zca_whitening=True)
4. datagen4 = ImageDataGenerator(rotation_range=90)
5. datagen5 = ImageDataGenerator(width_shift_range=shift, height_shift_range=shift)

Now, training a CNN model using datagen1:

[44]:
```
#training a model on augmented dataset
datagen1.fit(train_images_3d)
it = datagen1.flow(train_images_3d, to_categorical(train_emotions))



common_features = [Conv2D(32, kernel_size=3, activation='relu',␣
 ↪input_shape=(48,48,1)),
                Conv2D(32, kernel_size=3, activation='relu'),
                MaxPooling2D(pool_size=(2,2)),
                Conv2D(64, kernel_size=3, activation='relu'),
                Conv2D(64, kernel_size=3, activation='relu'),
            MaxPooling2D(pool_size=(2,2)), Flatten(),]
classifier = [Dense(512, activation='relu'), Dense(len(emotions),␣
 ↪activation='softmax'),]

cnn_model = Sequential(common_features+classifier)
cnn_model.compile(optimizer='adam',␣
 ↪loss='categorical_crossentropy',metrics=['accuracy'],)
history_cnn = cnn_model.fit_generator(it, epochs=10)
```

```
/usr/local/lib/python3.7/dist-packages/ipykernel_launcher.py:16: UserWarning:
`Model.fit_generator` is deprecated and will be removed in a future version.
Please use `Model.fit`, which supports generators.
  app.launch_new_instance()
```

```
Epoch 1/10
898/898 [==============================] - 69s 76ms/step - loss: 1.8030 -
accuracy: 0.2509
Epoch 2/10
898/898 [==============================] - 68s 76ms/step - loss: 1.7720 -
accuracy: 0.2677
Epoch 3/10
898/898 [==============================] - 69s 77ms/step - loss: 1.7104 -
accuracy: 0.3034
Epoch 4/10
898/898 [==============================] - 69s 77ms/step - loss: 1.6771 -
accuracy: 0.3227
Epoch 5/10
898/898 [==============================] - 69s 77ms/step - loss: 1.6565 -
accuracy: 0.3326
Epoch 6/10
898/898 [==============================] - 71s 79ms/step - loss: 1.6429 -
accuracy: 0.3403
Epoch 7/10
898/898 [==============================] - 70s 78ms/step - loss: 1.6280 -
accuracy: 0.3488
Epoch 8/10
898/898 [==============================] - 70s 78ms/step - loss: 1.6102 -
accuracy: 0.3577
Epoch 9/10
898/898 [==============================] - 70s 78ms/step - loss: 1.5926 -
accuracy: 0.3715
Epoch 10/10
898/898 [==============================] - 71s 79ms/step - loss: 1.5837 -
accuracy: 0.3755
```

The accuracy on the test dataset using this model is as follows:

[46]:
```python
performance = cnn_model.evaluate(test_images_3d, to_categorical(test_emotions))

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

```
113/113 [==============================] - 1s 9ms/step - loss: 2.1034 -
accuracy: 0.1677
Accuracy on Test samples: 0.16773474216461182
```

[29]:
```

```