CSCE 633 HW3

March 23, 2020

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[1]:
```python
import pandas as pd
import numpy as np
import matplotlib.pyplot as plt
```

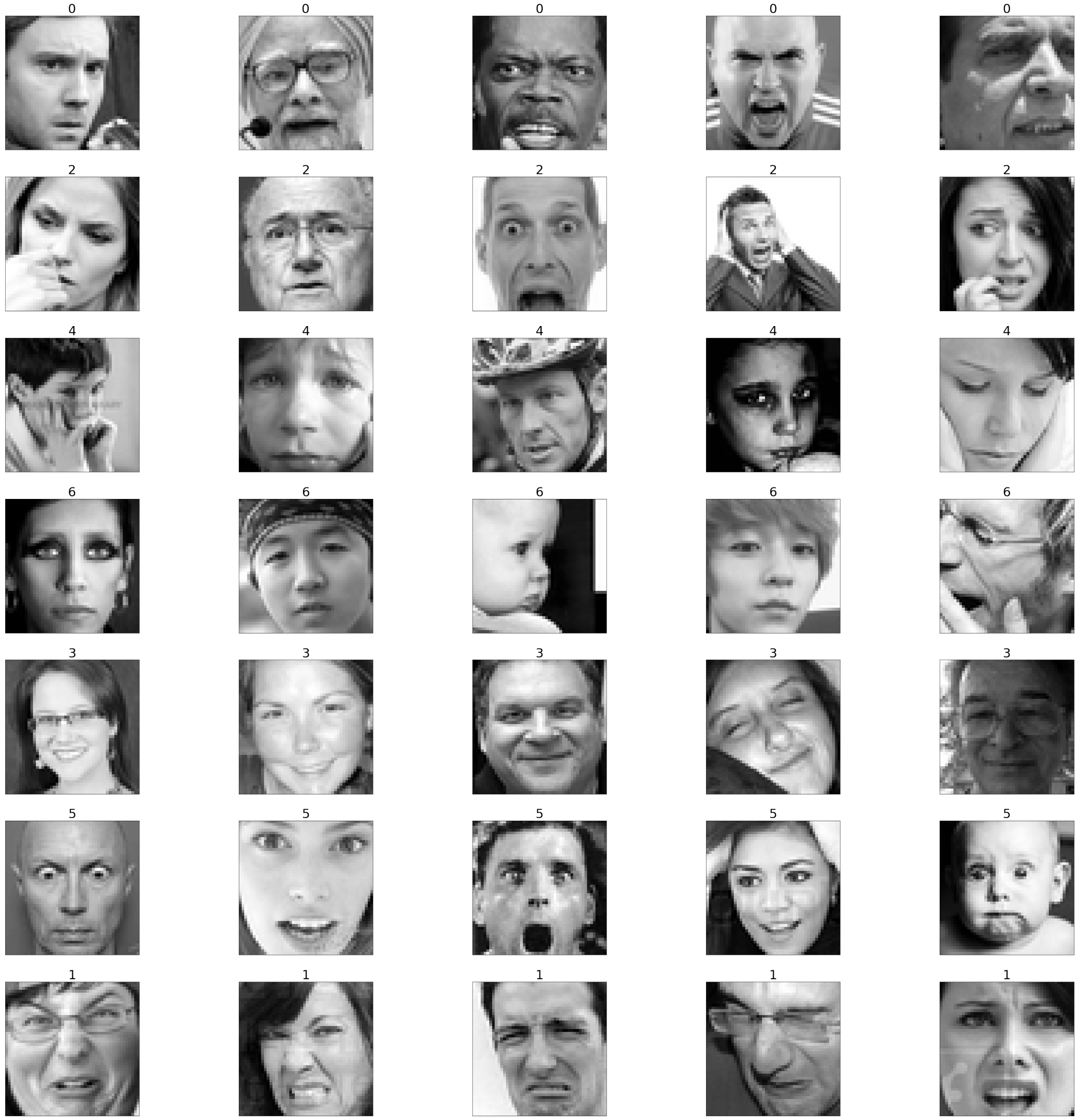
[2]:
```python
df_train_raw = pd.read_csv("Train_data.csv")
df_val_raw = pd.read_csv("Validation_data.csv")
df_test_raw = pd.read_csv("Test_data.csv")
```

[3]:
```python
train_images = df_train_raw['pixels'].str.split(' ', expand=True)
val_images = df_val_raw['pixels'].str.split(' ', expand=True)
test_images = df_test_raw['pixels'].str.split(' ', expand=True)

train_labels = df_train_raw['emotion']
val_labels = df_val_raw['emotion']
test_labels = df_test_raw['emotion']
```

[4]:
```python
train_images_raw = train_images.apply(pd.to_numeric)
val_images_raw = val_images.apply(pd.to_numeric)
test_images_raw = test_images.apply(pd.to_numeric)
```

1 (a) (1 point) Visualization:

[5]:
```python
emotion_sample_images = {}
fig = plt.figure(figsize=(48,48))
pic_id = 0

for emotion in train_labels.unique():
    images_ids = train_labels.loc[train_labels == emotion].index
    emotion_sample_images[emotion] = images_ids[:5]

    for idx in images_ids[:5]:
        ax = fig.add_subplot(7, 5, pic_id+1, xticks=[], yticks=[])
        ax.imshow(train_images_raw.iloc[idx,:].values.reshape(48, 48), cmap='gray')
        ax.set_title(str(emotion),fontsize=30)
        pic_id += 1
```



2 (b) (0.5 points) Data exploration:

[6]:
```
train_labels.value_counts()
```

```
[6]: 3    7215
     6    4965
     4    4830
     2    4097
     0    3995
     5    3171
     1     436
     Name: emotion, dtype: int64
```

```
[7]: from keras.regularizers import l2
     from keras.models import Sequential
     from keras.callbacks import EarlyStopping
     from keras.layers.advanced_activations import PReLU
     from keras.wrappers.scikit_learn import KerasClassifier
     from keras.layers.core import Dense, Dropout, Activation
     from keras.layers.normalization import BatchNormalization
     from sklearn.metrics import accuracy_score
     from sklearn.model_selection import RandomizedSearchCV
     # from sklearn.grid_search import b
     from keras.utils import to_categorical
```

```
Using TensorFlow backend.
```

```
[8]: from hyperopt import hp, fmin, tpe, STATUS_OK, Trials
     from keras.layers import Conv2D, Flatten, MaxPooling2D
     from keras import backend as K
     from hyperopt import space_eval

     import time
     import random
```

```
[9]: # pre-processing
     train_images_norm = (train_images_raw / 255) - 0.5
     val_images_norm = (val_images_raw / 255) - 0.5
     test_images_norm = (test_images_raw / 255) - 0.5
```

```
[10]: x_train_fnn = train_images_norm.copy()
      x_val_fnn = val_images_norm.copy()
      x_test_fnn = test_images_norm.copy()
```

```
[11]: y_train = to_categorical(train_labels)
      y_val = to_categorical(val_labels)
      y_test = to_categorical(test_labels)
```

```
[12]: n_input = train_images.shape[1]
      n_class = train_labels.unique().shape[0]
      print('feature num: ', n_input)
print('class num: ', n_class)
```

```
feature num:  2304
class num:  7
```

3 (c) (3.5 points) Image classification with FNNs

3.1 (c.i) (2.5 points)

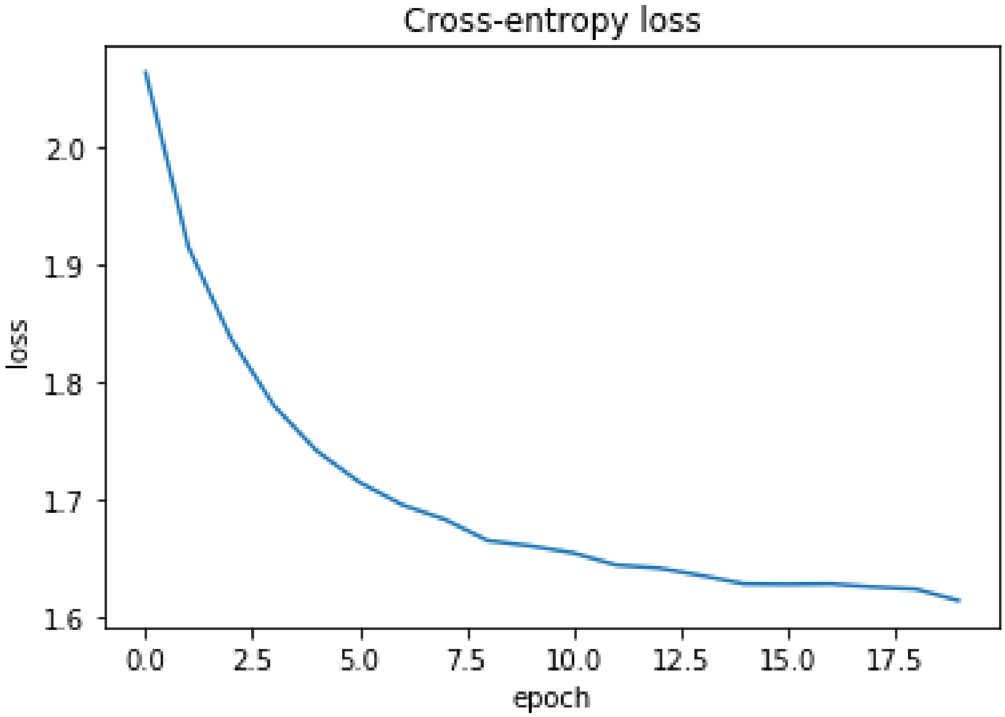
[13]:
```
K.clear_session()
```

[14]:
```
def optimize_fnn(hyperparameter):
  K.clear_session()
  fnn_model = Sequential()

  first_layer = True
  for layer_size in hyperparameter['network_config']:

    if first_layer:
        fnn_model.add(Dense(layer_size, input_dim = n_input,␣
↪activation=hyperparameter['activation_function'],kernel_regularizer =␣
↪l2(hyperparameter['l2_penalty']),))
        first_layer = False
    else:
        fnn_model.add(Dense(layer_size,␣
↪activation=hyperparameter['activation_function'],kernel_regularizer =␣
↪l2(hyperparameter['l2_penalty'])))

    fnn_model.add(Dropout(hyperparameter['dropout_prob']))

  fnn_model.add(Dense(n_class, activation='softmax'))

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

  train_X, train_y = train_images, y_train
  valid_X, valid_y = val_images, y_val

  start = time.time()
  fnn_history = fnn_model.fit(x_train_fnn, y_train, epochs=20, batch_size=256,␣
↪verbose=0)
  end = time.time()

#   print(fnn_model.summary())

  performance_fnn = fnn_model.evaluate(x_val_fnn, y_val, verbose=0)
  print("----------------------------------------------------")

  print("Hyperparameters: ", (hyperparameter))
  print()
  print("No. of parameters : %d" % (fnn_model.count_params()))
  print("Training time : %.2f s" % (end-start))
  print("Training Accuracy : %.3f" % (fnn_history.history['accuracy'][-1]))
  print("Validation Accuracy : %.3f" % (performance_fnn[1]))
  print("----------------------------------------------------")

  if random.random() < 0.35:
    plt.plot(fnn_history.history['loss'])
    plt.title('Cross-entropy loss')
    plt.ylabel('loss')
    plt.xlabel('epoch')
    plt.show()
    print("----------------------------------------------------")

# We want to minimize loss i.e. negative of accuracy
  return({"status": STATUS_OK, "loss": -1*performance_fnn[1], "model":fnn_model})
```

[15]:

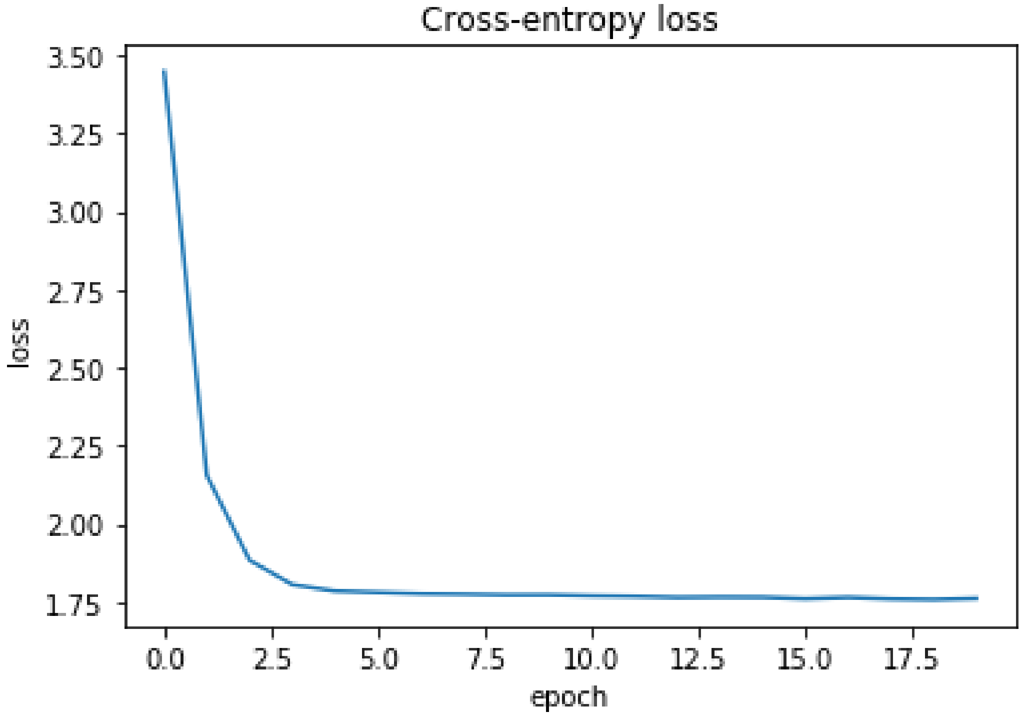
```
# Define search space for hyper-parameters
space_fnn = {
    # The kernel_size for convolutions:
    'network_config': hp.choice('network_config',␣
 ↪[[32,32,32],[32,64,128],[64,64],[64,128,64]]),
    # The stride_size for convolutions:
    'activation_function': hp.choice('activation_function', ['tanh', 'relu']),
    # Uniform distribution in finding appropriate dropout values
    'dropout_prob': hp.uniform('dropout_prob', 0.1, 0.35),
    # regularization:
    'l2_penalty': hp.choice('l2_penalty', [0.001,0.003,0.01,0.03]),
    # Choice of optimizer
    'optimizer': hp.choice('optimizer', ['Adam','sgd']),
}

trials_fnn = Trials()

# Find the best hyperparameters
best_fnn = fmin(
        optimize_fnn,
        space_fnn,
        algo=tpe.suggest,
        trials=trials_fnn,
        max_evals=10,
    )
```

```
----------------------------------------------------
Hyperparameters:
{'activation_function': 'relu', 'dropout_prob': 0.2658661419495981,
'l2_penalty': 0.001, 'network_config': (32, 32, 32), 'optimizer': 'Adam'}
No. of parameters : 76103
Training time : 38.27 s
Training Accuracy : 0.390
Validation Accuracy : 0.400
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'relu', 'dropout_prob': 0.34525558508915966,
'l2_penalty': 0.001, 'network_config': (64, 128, 64), 'optimizer': 'Adam'}
No. of parameters : 164551
Training time : 39.13 s
Training Accuracy : 0.406
Validation Accuracy : 0.408
----------------------------------------------------
 10%|                                           | 1/10 [01:18<05:54,
39.36s/trial, best loss: -0.3998328149318695]
```



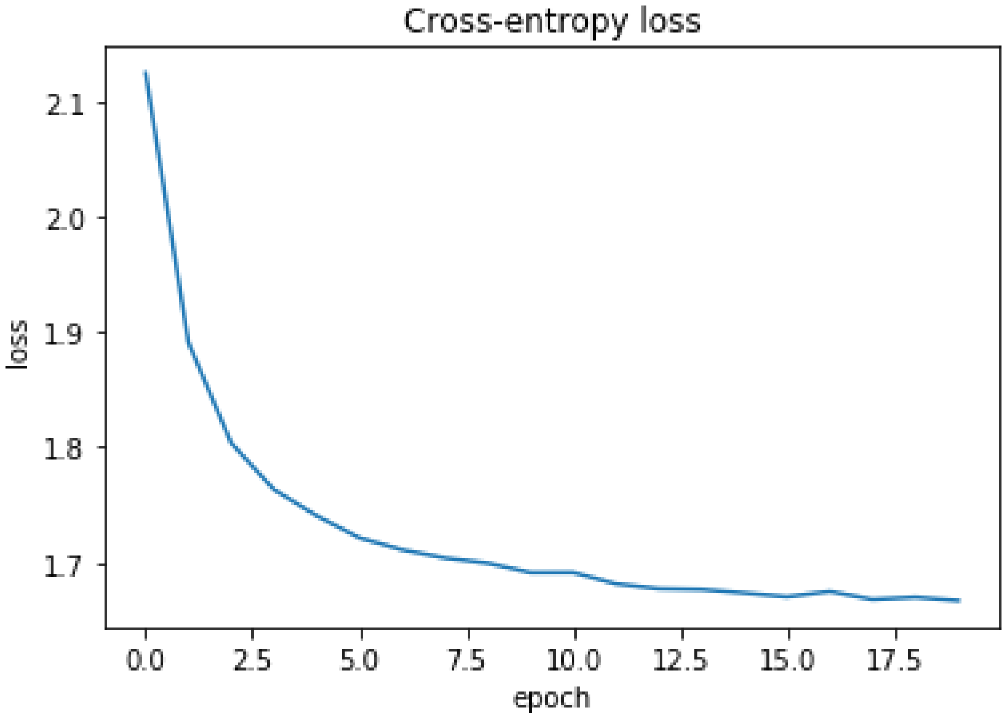
```
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
```

```
{'activation_function': 'tanh', 'dropout_prob': 0.1781299110474086,
'l2_penalty': 0.03, 'network_config': (32, 32, 32), 'optimizer': 'Adam'}
No. of parameters : 76103
Training time : 39.20 s
Training Accuracy : 0.318
Validation Accuracy : 0.339
----------------------------------------------------
 20%|                                       | 2/10 [01:58<05:15,
39.41s/trial, best loss: -0.407634437084198]
```

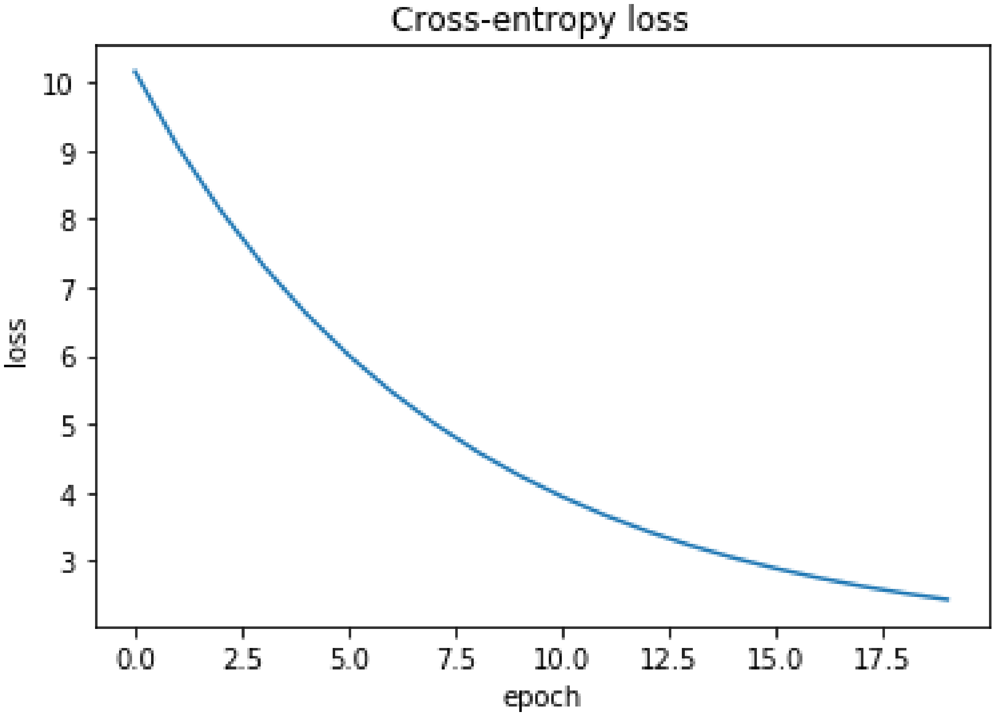


```
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'tanh', 'dropout_prob': 0.33285994826713994,
'l2_penalty': 0.003, 'network_config': (32, 64, 128), 'optimizer': 'Adam'}
No. of parameters : 85095
Training time : 39.04 s
Training Accuracy : 0.359
Validation Accuracy : 0.372
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'relu', 'dropout_prob': 0.23281380586559214,
'l2_penalty': 0.03, 'network_config': (32, 64, 128), 'optimizer': 'sgd'}
```

```
No. of parameters : 85095
Training time : 38.39 s
Training Accuracy : 0.262
Validation Accuracy : 0.264
---------------------------------------------------
---------------------------------------------------
Hyperparameters:
{'activation_function': 'relu', 'dropout_prob': 0.2224703044554185,
'l2_penalty': 0.003, 'network_config': (32, 32, 32), 'optimizer': 'Adam'}
No. of parameters : 76103
Training time : 38.38 s
Training Accuracy : 0.378
Validation Accuracy : 0.390
---------------------------------------------------
 50%|                        | 5/10 [03:55<03:15,
39.20s/trial, best loss: -0.407634437084198]
```



```
---------------------------------------------------
---------------------------------------------------
Hyperparameters:
{'activation_function': 'tanh', 'dropout_prob': 0.33050577093499756,
'l2_penalty': 0.03, 'network_config': (32, 32, 32), 'optimizer': 'Adam'}
No. of parameters : 76103
Training time : 37.62 s
Training Accuracy : 0.311
Validation Accuracy : 0.318
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'relu', 'dropout_prob': 0.22750854237118034,
'l2_penalty': 0.03, 'network_config': (64, 128, 64), 'optimizer': 'sgd'}
No. of parameters : 164551
Training time : 39.63 s
Training Accuracy : 0.276
Validation Accuracy : 0.284
----------------------------------------------------
 70%|             | 7/10 [05:13<01:56,
38.73s/trial, best loss: -0.407634437084198]
```



```
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'relu', 'dropout_prob': 0.17663707686718594,
'l2_penalty': 0.03, 'network_config': (64, 64), 'optimizer': 'sgd'}
No. of parameters : 152135
Training time : 38.40 s
Training Accuracy : 0.335
Validation Accuracy : 0.359
```

```
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'relu', 'dropout_prob': 0.2788555859969819,
'l2_penalty': 0.001, 'network_config': (32, 32, 32), 'optimizer': 'Adam'}
No. of parameters : 76103
Training time : 38.00 s
Training Accuracy : 0.387
Validation Accuracy : 0.405
----------------------------------------------------
100%|| 10/10 [06:30<00:00,
39.03s/trial, best loss: -0.407634437084198]
```

3.2 (c.ii) (1 point)

[16]:

```
print("==================================")
print("Best Hyperparameters", best_fnn)

best_hyper_fnn = space_eval(space_fnn,best_fnn)
fnn_tuned = optimize_fnn(best_hyper_fnn)

performance_fnn = fnn_tuned['model'].evaluate(x_test_fnn, y_test,verbose=0)

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

```
==================================
Best Hyperparameters {'activation_function': 1, 'dropout_prob':
0.34525558508915966, 'l2_penalty': 0, 'network_config': 3, 'optimizer': 0}
----------------------------------------------------
Hyperparameters:  {'activation_function': 'relu', 'dropout_prob':
0.34525558508915966, 'l2_penalty': 0.001, 'network_config': (64, 128, 64),
'optimizer': 'Adam'}

No. of parameters : 164551
Training time : 40.88 s
Training Accuracy : 0.405
Validation Accuracy : 0.408
----------------------------------------------------
==================================
Test Accuracy:  0.40930622816085815
```

FNN accuracy on test set: 0.4093

[17]:

```
x_train_cnn = train_images_norm.values.reshape((-1,48,48,1))
x_val_cnn = val_images_norm.values.reshape((-1,48,48,1))
x_test_cnn = test_images_norm.values.reshape((-1,48,48,1))
```

4 (d) (3 points) Image classification with CNNs:

4.1 (d.i) (2 points)

[18]:

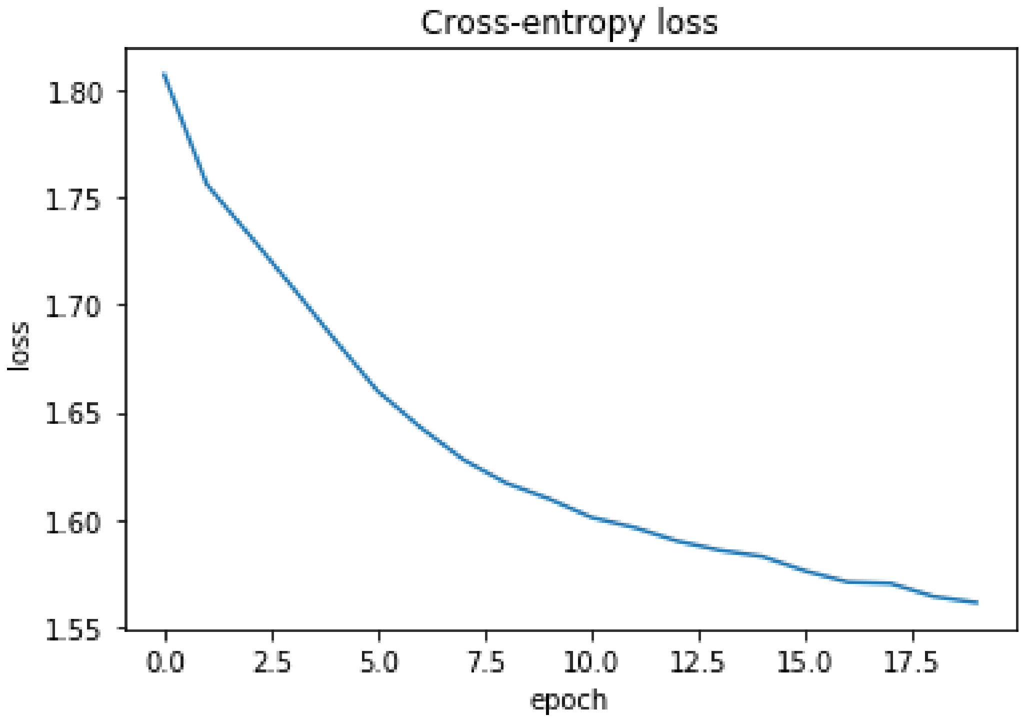
```
def optimize_cnn(hyperparameter):
  K.clear_session()
  cnn_model = Sequential()

  for layer_sequence in hyperparameter['conv2d_config']:
    for layer_size in layer_sequence:
        cnn_model.add(Conv2D(layer_size,␣
 ↪kernel_size=hyperparameter['conv_kernel_size'],padding='same',␣
 ↪strides=hyperparameter['stride_size'],␣
 ↪activation=hyperparameter['activation_function']))
    cnn_model.add(MaxPooling2D(pool_size=(2,2),padding='same'))
    cnn_model.add(Dropout(hyperparameter['dropout_prob']))

  cnn_model.add(Flatten())
  cnn_model.add(Dense(hyperparameter['dense_layer_neurons'],␣
 ↪activation=hyperparameter['activation_function']))

  cnn_model.add(Dense(7, activation='softmax'))

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

  start = time.time()
  cnn_history = cnn_model.fit(x_train_cnn, y_train, epochs=20, batch_size=256,␣
 ↪verbose=0)
  end = time.time()

#   print(cnn_model.summary())

  performance = cnn_model.evaluate(x_val_cnn, y_val, verbose=0)

  print("----------------------------------------------------")

  print("Hyperparameters: ", (hyperparameter))
  print()
  print("No. of parameters : %d" % (cnn_model.count_params()))
  print("Training time : %.2f s" % (end-start))
  print("Training Accuracy : %.3f" % (cnn_history.history['accuracy'][-1]))
  print("Validation Accuracy : %.3f" % (performance[1]))
  print("----------------------------------------------------")

  if random.random() < 0.35:
    plt.plot(cnn_history.history['loss'])
    plt.title('Cross-entropy loss')
    plt.ylabel('loss')
    plt.xlabel('epoch')
    plt.show()
    print("---------------------------------------------------")

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

[19]:

```
# Define search space for hyper-parameters
space_cnn = {
    # The convolution layers and sizes
    'conv2d_config': hp.choice('conv2d_config',␣
 ↪[[[32,32],[64,64]],[[32],[64],[128]]]),
    # The last dense layer size
    'dense_layer_neurons': hp.choice('dense_layer_neurons', [128,256]),
    # The kernel_size for convolutions:
    'conv_kernel_size': hp.choice('conv_kernel_size', [1, 3, 5]),
    # The stride_size for convolutions:
    'stride_size': hp.choice('stride_size', [1, 2]),
    # The activation function
    'activation_function': hp.choice('activation_function', ['tanh', 'relu']),
    # Uniform distribution in finding appropriate dropout values
    'dropout_prob': hp.uniform('dropout_prob', 0.1, 0.35),
    # Choice of optimizer
    'optimizer': hp.choice('optimizer', ['Adam','sgd']),
}

trials_cnn = Trials()

# Find the best hyperparameters
best_cnn = fmin(
        optimize_cnn,
        space_cnn,
        algo=tpe.suggest,
        trials=trials_cnn,
        max_evals=10,
    )
```

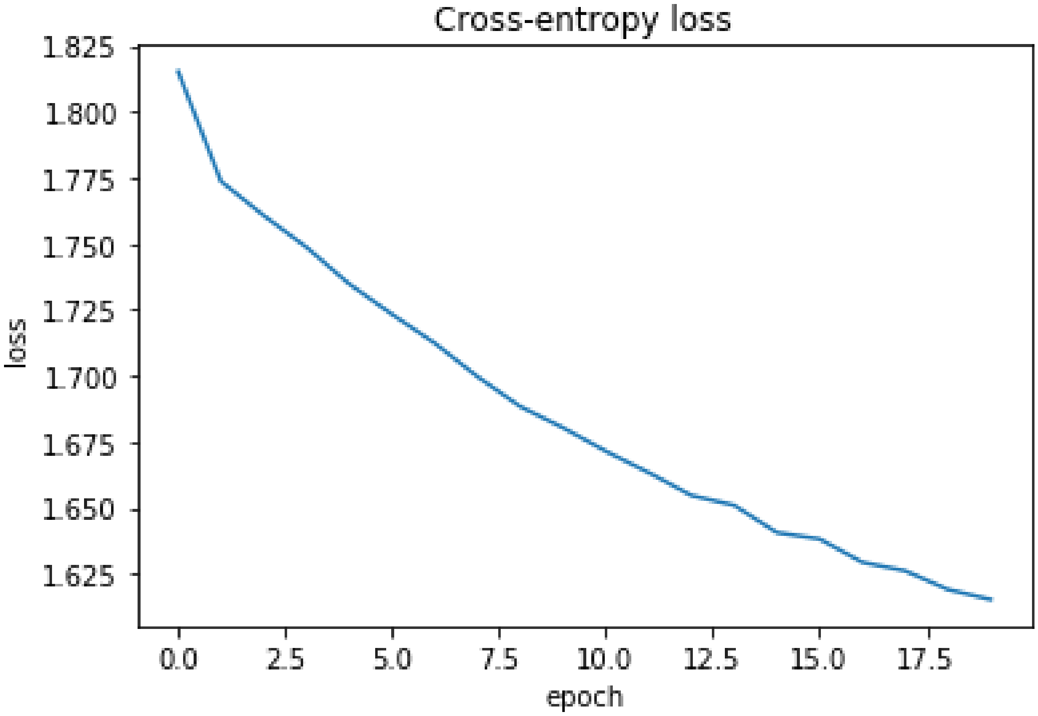
```
---------------------------------------------------
Hyperparameters:
{'activation_function': 'tanh', 'conv2d_config': ((32, 32), (64, 64)),
'conv_kernel_size': 1, 'dense_layer_neurons': 128, 'dropout_prob':
0.14596884626860737, 'optimizer': 'sgd', 'stride_size': 1}
No. of parameters : 1188071
Training time : 848.58 s
Training Accuracy : 0.401
```

```
Validation Accuracy : 0.378
----------------------------------------------------
  0%|
| 0/10 [14:10<?, ?trial/s, best loss=?]
```



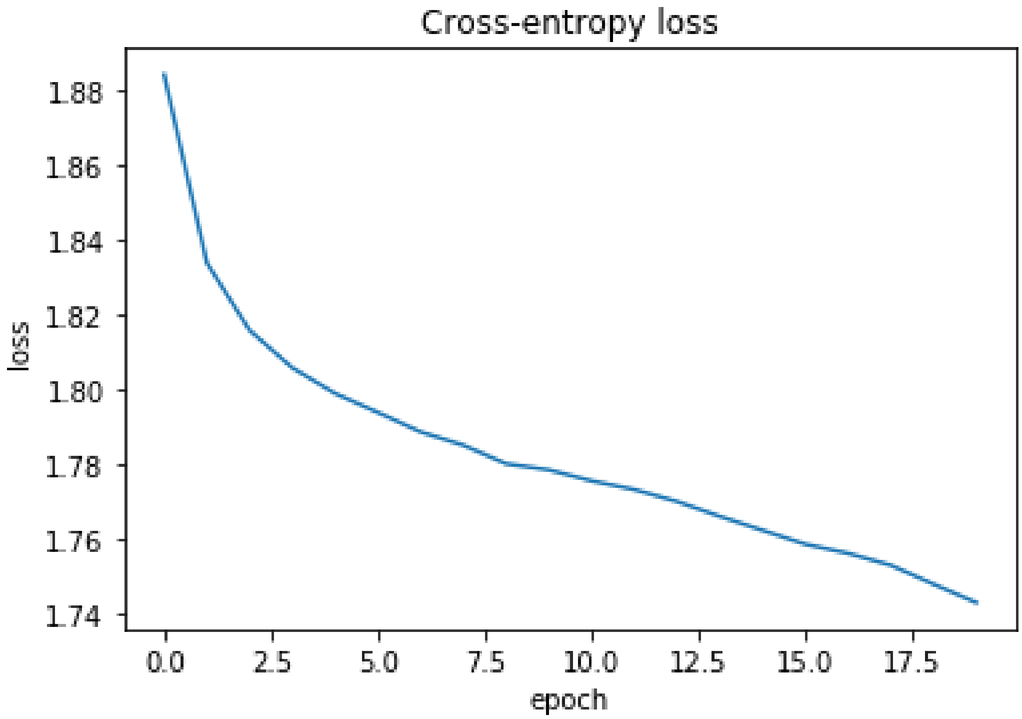
```
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'relu', 'conv2d_config': ((32, 32), (64, 64)),
'conv_kernel_size': 3, 'dense_layer_neurons': 256, 'dropout_prob':
0.2911961806773443, 'optimizer': 'Adam', 'stride_size': 1}
No. of parameters : 2426343
Training time : 3183.59 s
Training Accuracy : 0.947
Validation Accuracy : 0.587
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'relu', 'conv2d_config': ((32, 32), (64, 64)),
'conv_kernel_size': 1, 'dense_layer_neurons': 128, 'dropout_prob':
0.12362773461891252, 'optimizer': 'Adam', 'stride_size': 2}
No. of parameters : 16615
Training time : 227.52 s
Training Accuracy : 0.258
```

```
Validation Accuracy : 0.270
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'tanh', 'conv2d_config': ((32,), (64,), (128,)),
'conv_kernel_size': 3, 'dense_layer_neurons': 256, 'dropout_prob':
0.273851560737502, 'optimizer': 'sgd', 'stride_size': 1}
No. of parameters : 1274375
Training time : 1466.33 s
Training Accuracy : 0.371
Validation Accuracy : 0.367
----------------------------------------------------
 30%|                             | 3/10 [1:35:38<2:14:46,
1155.24s/trial, best loss: -0.5865143537521362]
```

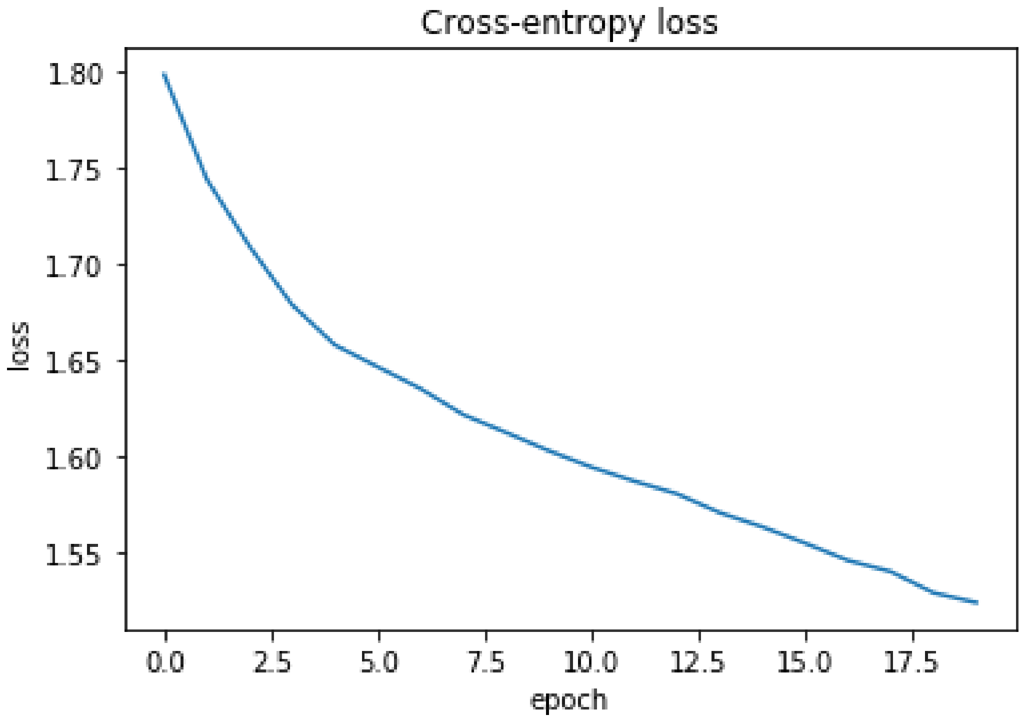


```
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'tanh', 'conv2d_config': ((32, 32), (64, 64)),
'conv_kernel_size': 3, 'dense_layer_neurons': 256, 'dropout_prob':
0.34119556919902994, 'optimizer': 'sgd', 'stride_size': 2}
No. of parameters : 83431
Training time : 183.41 s
Training Accuracy : 0.290
```

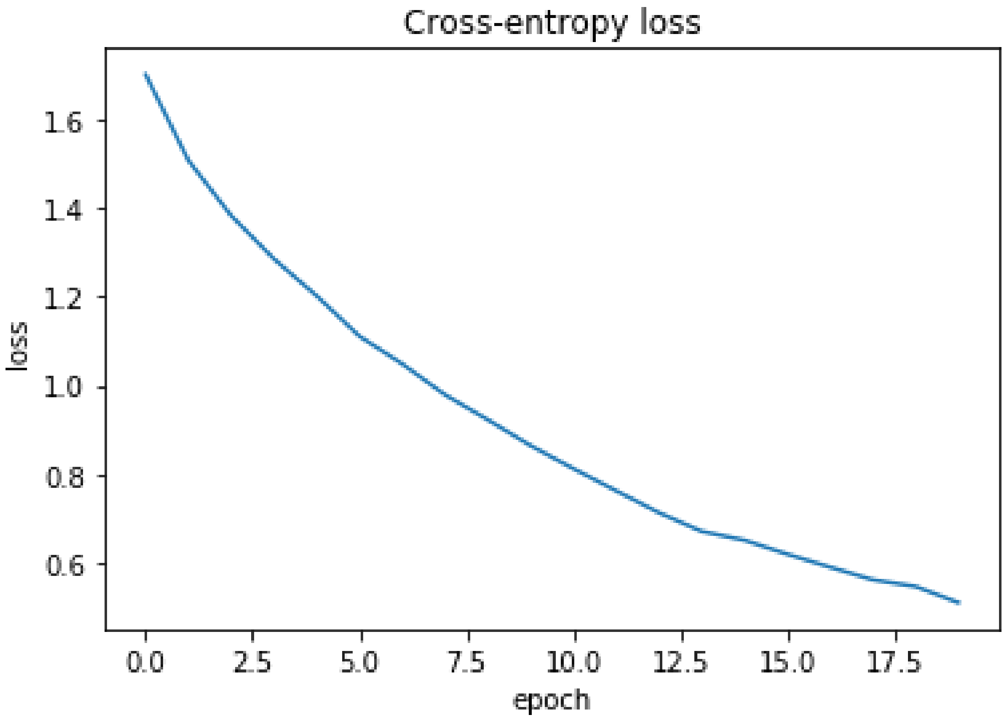
```
Validation Accuracy : 0.314
----------------------------------------------------
 40%|                         | 4/10 [1:38:42<2:04:56,
1249.34s/trial, best loss: -0.5865143537521362]
```



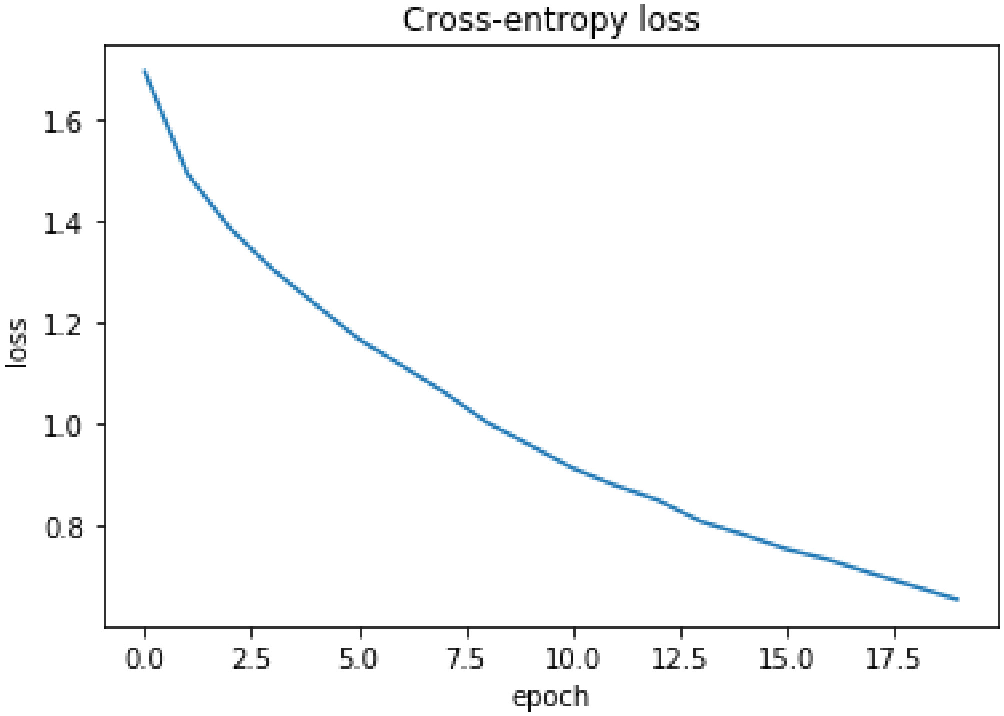
```
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'tanh', 'conv2d_config': ((32, 32), (64, 64)),
'conv_kernel_size': 3, 'dense_layer_neurons': 256, 'dropout_prob':
0.2818391037926066, 'optimizer': 'sgd', 'stride_size': 1}
No. of parameters : 2426343
Training time : 2536.79 s
Training Accuracy : 0.417
Validation Accuracy : 0.411
----------------------------------------------------
 50%|                     | 5/10 [2:21:03<1:17:29,
929.81s/trial, best loss: -0.5865143537521362]
```



```
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'tanh', 'conv2d_config': ((32,), (64,), (128,)),
'conv_kernel_size': 5, 'dense_layer_neurons': 256, 'dropout_prob':
0.13736009970345767, 'optimizer': 'Adam', 'stride_size': 2}
No. of parameters : 291847
Training time : 310.60 s
Training Accuracy : 0.815
Validation Accuracy : 0.539
----------------------------------------------------
 60%|                | 6/10 [2:26:16<1:34:12,
1413.23s/trial, best loss: -0.5865143537521362]
```



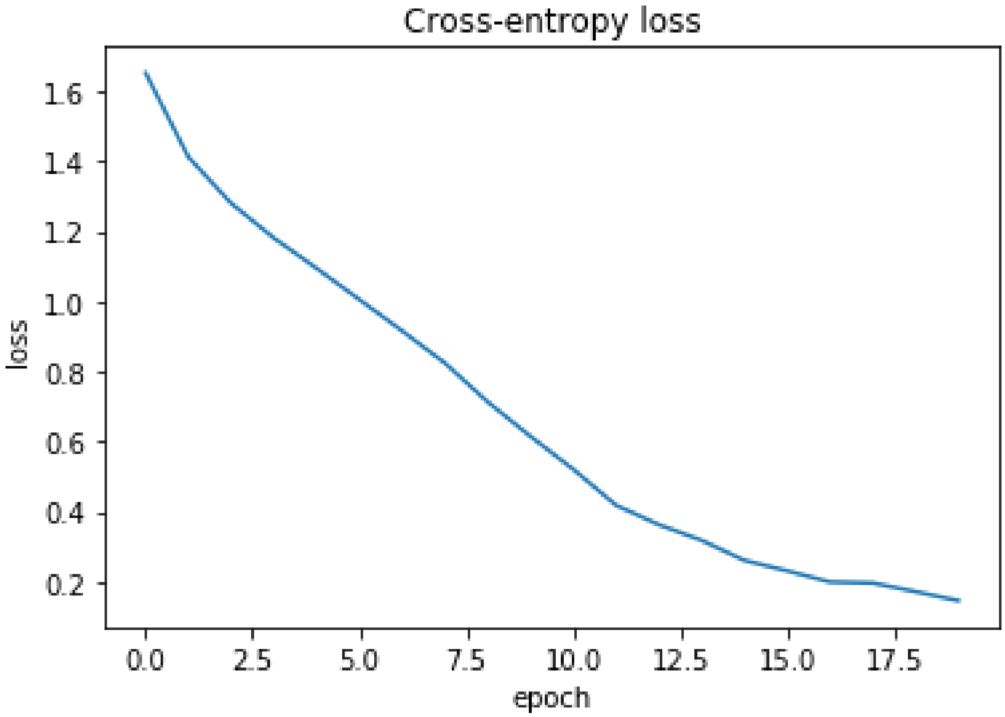
```
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'relu', 'conv2d_config': ((32,), (64,), (128,)),
'conv_kernel_size': 5, 'dense_layer_neurons': 128, 'dropout_prob':
0.25213564993880666, 'optimizer': 'Adam', 'stride_size': 2}
No. of parameters : 274439
Training time : 362.60 s
Training Accuracy : 0.596
Validation Accuracy : 0.549
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'relu', 'conv2d_config': ((32,), (64,), (128,)),
'conv_kernel_size': 3, 'dense_layer_neurons': 256, 'dropout_prob':
0.2008206210895777, 'optimizer': 'sgd', 'stride_size': 2}
No. of parameters : 127495
Training time : 294.81 s
Training Accuracy : 0.253
Validation Accuracy : 0.253
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'tanh', 'conv2d_config': ((32,), (64,), (128,)),
'conv_kernel_size': 5, 'dense_layer_neurons': 128, 'dropout_prob':
0.17873674765950004, 'optimizer': 'Adam', 'stride_size': 2}
No. of parameters : 274439
Training time : 367.63 s
Training Accuracy : 0.760
Validation Accuracy : 0.551
----------------------------------------------------
 90%|    | 9/10 [2:43:26<11:36,
696.10s/trial, best loss: -0.5865143537521362]
```



```
----------------------------------------------------
100%|| 10/10 [2:43:27<00:00,
980.72s/trial, best loss: -0.5865143537521362]
```

[20]:
```python
print("==================================")
print("Best Hyperparameters", best_cnn)

best_hyper_cnn = space_eval(space_cnn,best_cnn)
cnn_tuned = optimize_cnn(best_hyper_cnn)

performance_cnn = cnn_tuned['model'].evaluate(x_test_cnn, y_test,verbose=0)

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

```
==================================
Best Hyperparameters {'activation_function': 1, 'conv2d_config': 0,
'conv_kernel_size': 1, 'dense_layer_neurons': 1, 'dropout_prob':
0.2911961806773443, 'optimizer': 0, 'stride_size': 0}
----------------------------------------------------
Hyperparameters:  {'activation_function': 'relu', 'conv2d_config': ((32, 32),
(64, 64)), 'conv_kernel_size': 3, 'dense_layer_neurons': 256, 'dropout_prob':
0.2911961806773443, 'optimizer': 'Adam', 'stride_size': 1}

No. of parameters : 2426343
Training time : 5303.13 s
Training Accuracy : 0.949
Validation Accuracy : 0.582
----------------------------------------------------
```



```
----------------------------------------------------
==================================
Test Accuracy:  0.5828921794891357
```

CNN accuracy on test set: 0.5829

4.2 FNN and CNN comparision

	FNN	CNN
No. of parameters	< 200K	> 1M
Training time	< 1 min	> 5 min
Best Training accuracy	0.405	0.949
Best Validation accuracy	0.408	0.582
Test accuracy	0.409	0.582

Conclusion: We get improvement in our predictions using CNN over FNN.

5 (d) (2 points) Fine-tuning:

[21]:
```
from keras.applications.vgg16 import VGG16
from keras.preprocessing import image
from keras.applications.vgg16 import preprocess_input
from keras.layers import Input, Flatten, Dense
from keras.models import Model, load_model
from keras.datasets import mnist
```

[22]:
```
# Convert the images into 3 channels
x_train_rgb=np.dstack([train_images_norm] * 3)
x_val_rgb=np.dstack([val_images_norm]*3)
x_test_rgb=np.dstack([test_images_norm]*3)
x_train_vgg = x_train_rgb.reshape(-1,48,48,3)
x_val_vgg= x_val_rgb.reshape (-1,48,48,3)
x_test_vgg= x_test_rgb.reshape (-1,48,48,3)
```

[23]:
```
fer_shape = x_train_vgg.shape[1:]
```

[27]:
```
def optimize_vgg(hyperparameter):
    K.clear_session()
    vgg_pretrain = VGG16(weights='imagenet', include_top=False)

    for layer in vgg_pretrain.layers[:hyperparameter['unfreeze_layers']]:
        layer.trainable = False

    fer_input = Input(shape=fer_shape, name = 'image_input')
    vgg_output = vgg_pretrain(fer_input)
    x = Flatten(name='flatten')(vgg_output)

    for layer_size in hyperparameter['add_config']:
        x = Dense(layer_size,␣
 ↪activation=hyperparameter['activation_function'],kernel_regularizer =␣
 ↪l2(hyperparameter['l2_penalty']))(x)
        x = Dropout(hyperparameter['dropout_prob'])(x)
    x = Dense(n_class, activation='softmax', name='predictions')(x)

    fer_pretrained = Model(inputs=fer_input, outputs=x)
    fer_pretrained.compile(loss='categorical_crossentropy', optimizer='adam',␣
 ↪metrics=['accuracy'])

    start = time.time()
    vgg_history = fer_pretrained.fit(x_train_vgg, y_train, epochs=2,␣
 ↪batch_size=256, verbose=0)
    end = time.time()

    performance = fer_pretrained.evaluate(x_val_vgg, y_val, verbose=0)

    print("----------------------------------------------------")

    print("Hyperparameters: ", (hyperparameter))
    print()
    print("No. of parameters : %d" % (fer_pretrained.count_params()))
    print("Training time : %.2f s" % (end-start))
    print("Training Accuracy : %.3f" % (vgg_history.history['accuracy'][-1]))
    print("Validation Accuracy : %.3f" % (performance[1]))
    print("----------------------------------------------------")

    if random.random() < 0.35:
        plt.plot(vgg_history.history['loss'])
        plt.title('Cross-entropy loss')
        plt.ylabel('loss')
        plt.xlabel('epoch')
        plt.show()
        print("----------------------------------------------------")

    # We want to minimize loss i.e. negative of accuracy
    return({"status": STATUS_OK, "loss": -1*performance[1], "model":␣
 ↪fer_pretrained})
```

[28]:

```
# Define search space for hyper-parameters
space_vgg = {
    # The convolution layers and sizes
    'add_config': hp.choice('add_config', [[128,32],[256,64]]),
    # The activation function
    'activation_function': hp.choice('activation_function', ['tanh', 'relu']),
    # Uniform distribution in finding appropriate dropout values
    'dropout_prob': hp.uniform('dropout_prob', 0.1, 0.35),
    'unfreeze_layers': hp.choice('unfreeze_layers', [4,5]),
    # regularization:
    'l2_penalty': hp.choice('l2_penalty', [0.001,0.003,0.01,0.03]),
}
```

```python
trials_vgg = Trials()

# Find the best hyperparameters
best_vgg = fmin(
        optimize_vgg,
        space_vgg,
        algo=tpe.suggest,
        trials=trials_vgg,
        max_evals=5,
    )
```

```
----------------------------------------------------
Hyperparameters:
{'activation_function': 'relu', 'add_config': (128, 32), 'dropout_prob':
0.18526718592673108, 'l2_penalty': 0.01, 'unfreeze_layers': 4}
No. of parameters : 14784711
Training time : 530.47 s
Training Accuracy : 0.221
Validation Accuracy : 0.249
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'relu', 'add_config': (128, 32), 'dropout_prob':
0.34545365334991956, 'l2_penalty': 0.001, 'unfreeze_layers': 5}
No. of parameters : 14784711
Training time : 512.90 s
Training Accuracy : 0.226
Validation Accuracy : 0.249
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'tanh', 'add_config': (128, 32), 'dropout_prob':
0.17201805991803998, 'l2_penalty': 0.003, 'unfreeze_layers': 5}
No. of parameters : 14784711
Training time : 1793.18 s
Training Accuracy : 0.200
Validation Accuracy : 0.249
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'relu', 'add_config': (256, 64), 'dropout_prob':
0.24408521902718688, 'l2_penalty': 0.001, 'unfreeze_layers': 4}
No. of parameters : 14862919
Training time : 384.16 s
Training Accuracy : 0.228
Validation Accuracy : 0.249
```

```
----------------------------------------------------
----------------------------------------------------
Hyperparameters:
{'activation_function': 'tanh', 'add_config': (256, 64), 'dropout_prob':
0.3287684730760788, 'l2_penalty': 0.001, 'unfreeze_layers': 4}
No. of parameters : 14862919
Training time : 378.46 s
Training Accuracy : 0.184
Validation Accuracy : 0.169
----------------------------------------------------
100%|| 5/5 [1:03:22<00:00,
760.42s/trial, best loss: -0.24937307834625244]
```

[29]:

```python
print("==================================")
print("Best Hyperparameters", best_vgg)

best_hyper_vgg = space_eval(space_vgg,best_vgg)
vgg_tuned = optimize_vgg(best_hyper_vgg)

performance_vgg = vgg_tuned['model'].evaluate(x_test_vgg, y_test,verbose=0)

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

```
==================================
Best Hyperparameters {'activation_function': 1, 'add_config': 0, 'dropout_prob':
0.18526718592673108, 'l2_penalty': 2, 'unfreeze_layers': 0}
----------------------------------------------------
Hyperparameters:  {'activation_function': 'relu', 'add_config': (128, 32),
'dropout_prob': 0.18526718592673108, 'l2_penalty': 0.01, 'unfreeze_layers': 4}

No. of parameters : 14784711
Training time : 404.27 s
Training Accuracy : 0.242
Validation Accuracy : 0.249
----------------------------------------------------

----------------------------------------------------
==================================
Test Accuracy:  0.24491502344608307
```

Fine-Tuning accuracy on the test set: 0.2449