Lab2_Q2

March 20, 2020

ComS 573

Lab 2

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1 Problem 2

For this problem, I have used the following parameter combinations

```
hid_layer = [2,3]
num_epochs = [80, 100, 120]
btch_size = [128, 200]
learning_rate = [0.05, 0.1, 0.2]
momentum = [.5, 0.9, 1]
los = ['categorical_crossentropy']
scale = ['Standardize', 'Normalize']
activ = ['relu']
filters = [64, 32]
kernel_size = [(3,3), (4, 4)]
```

Also used 80% - 20% training - validation data.

[1]:
```
import numpy as np
import pandas as pd
import sklearn.preprocessing
import matplotlib
import keras
import re
import sys
import gc
import time

print('python ' +sys.version)
print('numpy '+ np.__version__)
print('pandas '+ pd.__version__)
print('sklearn '+ sklearn.__version__)
print('matplotlib '+ matplotlib.__version__)
print('keras '+ keras.__version__)
print('re '+ re.__version__)
```

```
from sklearn.preprocessing import StandardScaler
from sklearn.preprocessing import Normalizer
from sklearn.metrics import confusion_matrix
from matplotlib import pyplot as plt

from keras import optimizers
from keras.models import Sequential
from keras.layers import Dense, Dropout, Flatten
from keras.layers import Convolution2D, MaxPooling2D
from keras.utils import np_utils
from keras.callbacks import EarlyStopping
from keras.callbacks import ModelCheckpoint
from keras.models import load_model
from itertools import product
```

```
Using TensorFlow backend.
```

```
python 3.7.6 (default, Jan  8 2020, 20:23:39) [MSC v.1916 64 bit (AMD64)]
numpy 1.18.1
pandas 1.0.1
sklearn 0.22.1
matplotlib 3.1.3
keras 2.3.1
re 2.2.1
```

[2]:
```
path  = 'D:/ISU/COMS 573 - Machine Learning/HW/Lab2/'

train_model = False

df_tr = pd.read_csv(path+'optdigits.tra',header=None)
X_tr, y_tr = df_tr.loc[:,0:63], df_tr.loc[:,64]
ccat = y_tr.unique().size

df_ts = pd.read_csv(path+'optdigits.tes',header=None)
X_ts,  y_ts  = df_ts.loc[:,0:63],  df_ts.loc[:,64]

scaler = StandardScaler().fit(X_tr)
normalizer = Normalizer().fit(X_tr)

X_tr_std = scaler.transform(X_tr)
X_tr_norm = normalizer.transform(X_tr)


split = 0.8
size = np.shape(X_tr)
nsplit = int(np.floor(split*size[0]))
```

```
y_train1 = np_utils.to_categorical(y_tr, ccat)
y_train = y_train1[0:nsplit,:];
y_val = y_train1[nsplit:size[0],:];
y_test = np_utils.to_categorical(y_ts, ccat)


X_train_std = X_tr_std[0:nsplit,:];
X_val_std = X_tr_std[nsplit:size[0],:];
X_test_std = scaler.transform(X_ts)

X_train_std = X_train_std.reshape(-1, 8, 8, 1)
X_val_std = X_val_std.reshape(-1, 8, 8, 1)
X_test_std = X_test_std.reshape(-1, 8, 8, 1)



X_train_norm = X_tr_norm[0:nsplit,:];
X_val_norm = X_tr_norm[nsplit:size[0],:];
X_test_norm = normalizer.transform(X_ts)

X_train_norm = X_train_norm.reshape(-1, 8, 8, 1)
X_val_norm = X_val_norm.reshape(-1, 8, 8, 1)
X_test_norm = X_test_norm.reshape(-1, 8, 8, 1)
```

[3]:
```
if train_model:
    hid_layer = [2,3]
    num_epochs = [80, 100, 120]
    btch_size = [128, 200]
    learning_rate = [0.05, 0.1, 0.2]
    momentum = [.5, 0.9, 1]
    los = ['categorical_crossentropy']
    scale = ['Standardize', 'Normalize']
    activ = ['relu']
    filters = [64, 32]
    kernel_size = [(3,3), (4, 4)]


    def expand_grid(dictionary):
       return pd.DataFrame([row for row in product(*dictionary.values())],
                           columns=dictionary.keys())

    dictionary = {'hidden_layers': hid_layer,
                  'filters': filters,
                  'num_epochs': num_epochs,
                  'batch_size': btch_size,
                  'learning_rate': learning_rate,
                  'momentum': momentum,
```

```
                  'loss_func': los,
                  'data_scaling': scale,
                  'activation_func': activ,
                  'kernel_size': kernel_size}

   prem1 = expand_grid(dictionary)
   prem1 = prem1[~((prem1['activation_func'] == 'tanh') & (prem1['loss_func'] == 'mean_squared_error'))]
   prem1['time'] = np.NaN
   prem1['train_loss'] = np.NaN
   prem1['validation_loss'] = np.NaN
   prem1['test_loss'] = np.NaN
   prem1['train_acc'] = np.NaN
   prem1['validation_acc'] = np.NaN
   prem1['test_acc'] = np.NaN
   size_prem1 = prem1.shape
   print(prem1.head())

   ll = 0
   for j in range(0,2):
       if j == 0:
           X_train = X_train_std
           X_val = X_val_std
           X_test = X_test_std
           listind = prem1[prem1['data_scaling'] == 'Standardize'].index.tolist()
       else:
           X_train = X_train_norm
           X_val = X_val_norm
           X_test = X_test_norm
           listind = prem1[prem1['data_scaling'] == 'Normalize'].index.tolist()

       for i in listind:
           try:
               start = time. time()
               if prem1.iloc[i,0] == 1:
                   model = Sequential()
                   model.add(Convolution2D(filters = 64, kernel_size= prem1.iloc[i,9],
                                           input_shape=(8,8,1), activation='relu', padding='valid'))
                   model.add(MaxPooling2D(pool_size=(2,2), padding='valid'))
                   model.add(Dropout(0.3))
                   model.add(Flatten())
                   model.add(Dense(10, activation='softmax'))

               elif prem1.iloc[i,0] == 2:
```

```
            model = Sequential()
            model.add(Convolution2D(filters = 64, kernel_size= prem1.
↪iloc[i,9],
                                    input_shape=(8,8,1),␣
↪activation='relu', padding='valid'))
            model.add(Convolution2D(filters = prem1.iloc[i,1],␣
↪kernel_size= prem1.iloc[i,9], padding='valid'))
            model.add(MaxPooling2D(pool_size=(2,2), padding='valid'))
            model.add(Dropout(0.3))
            model.add(Flatten())
            model.add(Dense(10, activation='softmax'))

        else:
            model = Sequential()
            model.add(Convolution2D(filters = 64, kernel_size= prem1.
↪iloc[i,9],
                                    input_shape=(8,8,1),␣
↪activation='relu', padding='valid'))
            model.add(Convolution2D(filters = prem1.iloc[i,1],␣
↪kernel_size= prem1.iloc[i,9], padding='valid'))
            model.add(Convolution2D(filters = prem1.iloc[i,1],␣
↪kernel_size= prem1.iloc[i,9], padding='valid'))
            model.add(MaxPooling2D(pool_size=(2,2), padding='valid'))
            model.add(Dropout(0.3))
            model.add(Flatten())
            model.add(Dense(10, activation='softmax'))


        es = EarlyStopping(monitor='val_accuracy', mode='max',␣
↪verbose=0, patience=200)
        mc = ModelCheckpoint('best_model', monitor='val_accuracy',␣
↪mode='max', verbose=0, save_best_only=True)


        optimizer1 = optimizers.SGD(lr=prem1.iloc[i,4], momentum=prem1.
↪iloc[i,5])
        model.compile(optimizer=optimizer1, loss=prem1.iloc[i,6],␣
↪metrics=['accuracy'])
        fit1 = model.fit(X_train,y_train, batch_size=prem1.iloc[i,3],␣
↪epochs=prem1.iloc[i,2],
                         validation_data=(X_val,y_val), callbacks=[es,␣
↪mc], verbose = 0)
        fit = load_model('best_model')
        end = time.time()
        train_accuracy = fit.evaluate(X_train, y_train, verbose=0)
        val_accuracy = fit.evaluate(X_val, y_val, verbose=0)
```

```
                test_accuracy = fit.evaluate(X_test, y_test, verbose=0)
                prem1.iloc[i, 10:17] = [end-start, train_accuracy[0],␣
↪val_accuracy[0], test_accuracy[0],
                                      train_accuracy[1], val_accuracy[1],␣
↪test_accuracy[1]]


                del model, es, mc, optimizer1, fit, fit1
                gc.collect()
            except:
                pass
            finally:
                ll = ll+1
                sys.stdout.write("\r Progress: %.2f%%" %round(float(ll)/
↪size_prem1[0]*100,2))
                sys.stdout.flush()
else:
    print('skiped model fit')
```

```
skiped model fit
```

[4]:
```
if train_model:
    prem1.to_csv (path+'res_2.csv', index = False, header=True)
    prem = prem1
else:
    prem = pd.read_csv(path+'res_2.csv',header=0)
    prem.head()

    kk1 = []
    for i in range(prem.shape[0]):
        kk1.append(tuple(map(int, prem.iloc[i,9].replace('(', '').replace(')',␣
↪'').replace(' ', '').split(','))))
    prem['kernel_size'] = kk1

top10_cce = prem[prem['loss_func'] == 'categorical_crossentropy'].
↪nlargest(10,'test_acc')
print('\n Best 10 hyper-parameter combination for Cross-Entropy:\n',␣
↪round(top10_cce, 4))


plt.hist(prem.iloc[:,10],  density=True, alpha=0.5, label=['CNN'])
plt.legend(loc='upper right')
plt.title('Distribution of time to fit models')
# plt.xlim(0, 200)
plt.show()

plt.hist(prem.iloc[:,16],
```

```
        density=True, alpha=0.5, label=['CNN'])
plt.legend(loc='upper left')
plt.title('Distribution of test accuracy')
plt.show()
```

Best 10 hyper-parameter combination for Cross-Entropy:

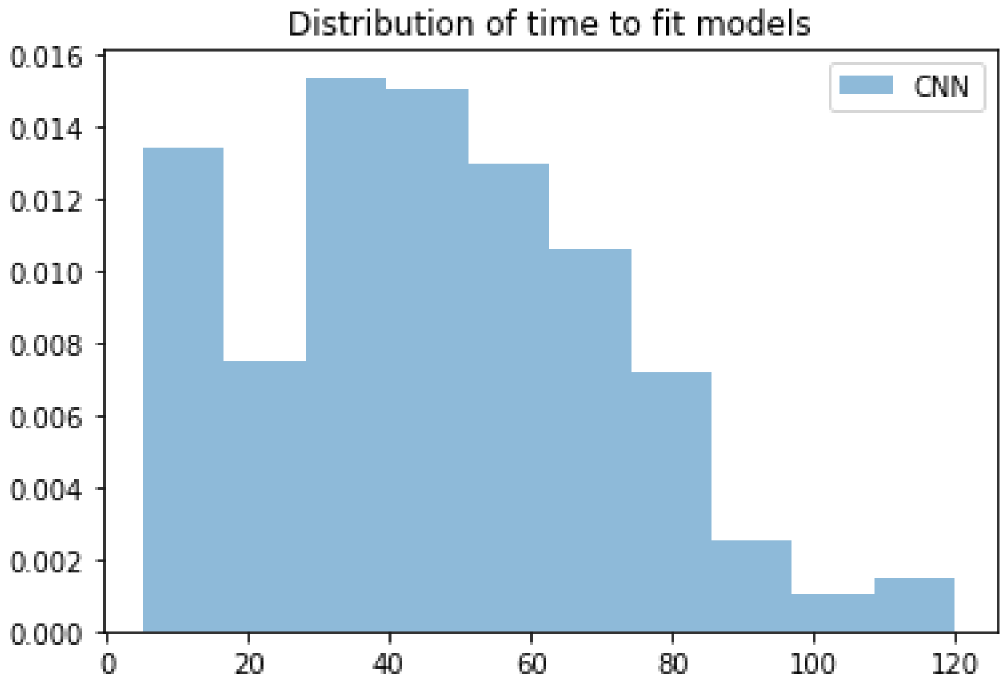
	hidden_layers	filters	num_epochs	batch_size	learning_rate	momentum \
509	3	64	100	128	0.20	0.5
487	3	64	80	128	0.05	0.9
521	3	64	120	128	0.05	0.9
579	3	32	120	200	0.10	0.5
580	3	32	120	200	0.10	0.9
547	3	32	80	200	0.10	0.5
556	3	32	100	128	0.10	0.5
332	2	64	100	200	0.10	0.9
355	2	64	120	128	0.20	0.5
374	2	64	120	200	0.20	0.9

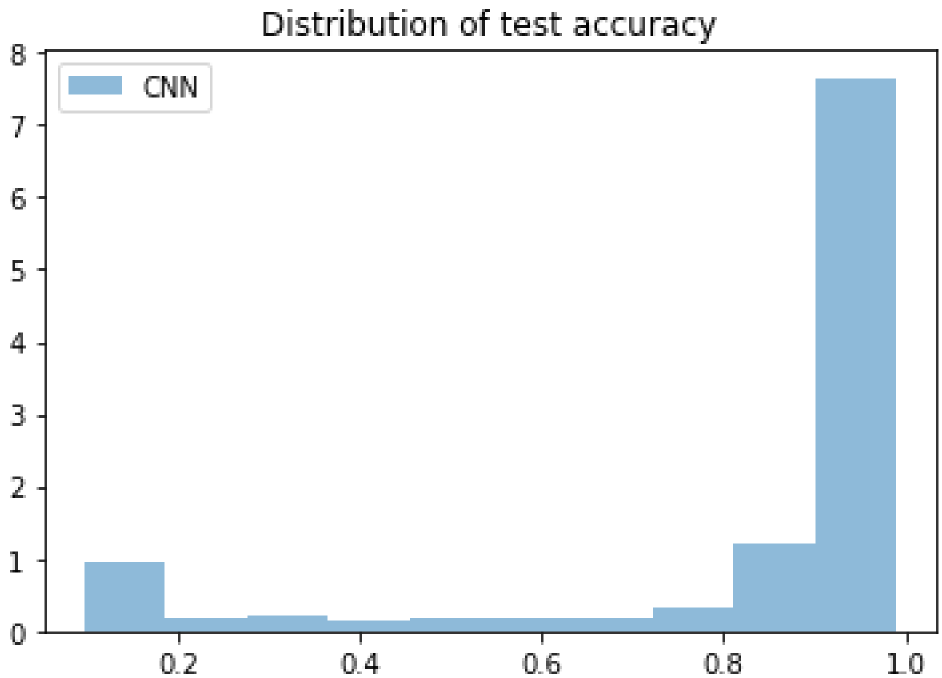
	loss_func	data_scaling	activation_func	kernel_size \
509	categorical_crossentropy	Standardize	relu	(3, 3)
487	categorical_crossentropy	Standardize	relu	(3, 3)
521	categorical_crossentropy	Standardize	relu	(3, 3)
579	categorical_crossentropy	Standardize	relu	(3, 3)
580	categorical_crossentropy	Standardize	relu	(3, 3)
547	categorical_crossentropy	Standardize	relu	(3, 3)
556	categorical_crossentropy	Standardize	relu	(3, 3)
332	categorical_crossentropy	Standardize	relu	(3, 3)
355	categorical_crossentropy	Standardize	relu	(4, 4)
374	categorical_crossentropy	Standardize	relu	(3, 3)

	time	train_loss	validation_loss	test_loss	train_acc \
509	104.5165	0.0000	0.0481	0.0407	1.0000
487	75.6567	0.0003	0.0335	0.0501	1.0000
521	119.9278	0.0001	0.0758	0.0475	1.0000
579	85.3661	0.0006	0.0615	0.0466	1.0000
580	81.9683	0.0001	0.0906	0.0623	1.0000
547	59.1002	0.0020	0.0466	0.0584	0.9997
556	81.4093	0.0028	0.0394	0.0414	0.9993
332	71.7168	0.0001	0.0537	0.0632	1.0000
355	54.8639	0.0002	0.0415	0.0633	1.0000
374	67.5542	0.0000	0.0308	0.0681	1.0000

	validation_acc	test_acc
509	0.9922	0.9900
487	0.9948	0.9878
521	0.9895	0.9878

579	0.9908	0.9878
580	0.9935	0.9872
547	0.9935	0.9866
556	0.9935	0.9866
332	0.9935	0.9861
355	0.9935	0.9861
374	0.9961	0.9861





[5]:
```
aaa = prem.iloc[:,10]
print("Mean and Variance of fitted time:\n CNN: Mean = %.2f, \
var = %.2f\n" %(np.mean(aaa), np.var(aaa)))

aaa = prem.iloc[:,16]
print("Mean and Variance of test accuracy:\n CNN: Mean = %.4f, \
var = %.4f\n" %(np.mean(aaa), np.var(aaa)))
```

```
Mean and Variance of fitted time:
 CNN: Mean = 46.11, var = 655.43

Mean and Variance of test accuracy:
 CNN: Mean = 0.8302, var = 0.0736
```

[6]:
```
top10 = top10_cce
print("\n Results For CNN")
print("******************************************\n")


if top10.iloc[0,7] == 'Standardize':
    X_train = X_train_std
    X_val = X_val_std
    X_test = X_test_std
else:
```

```
    X_train = X_train_norm
    X_val = X_val_norm
    X_test = X_test_norm


start = time. time()
if top10.iloc[0,0] == 1:
    model = Sequential()
    model.add(Convolution2D(filters = 64, kernel_size= top10.iloc[0,9],
                            input_shape=(8,8,1), activation='relu',␣
 ↪padding='valid'))
    model.add(MaxPooling2D(pool_size=(2,2), padding='valid'))
    model.add(Dropout(0.3))
    model.add(Flatten())
    model.add(Dense(10, activation='softmax'))

elif top10.iloc[0,0] == 2:
    model = Sequential()
    model.add(Convolution2D(filters = 64, kernel_size= top10.iloc[0,9],
                            input_shape=(8,8,1), activation='relu',␣
 ↪padding='valid'))
    model.add(Convolution2D(filters = top10.iloc[0,1], kernel_size= top10.
 ↪iloc[0,9], padding='valid'))
    model.add(MaxPooling2D(pool_size=(2,2), padding='valid'))
    model.add(Dropout(0.3))
    model.add(Flatten())
    model.add(Dense(10, activation='softmax'))

else:
    model = Sequential()
    model.add(Convolution2D(filters = 64, kernel_size= top10.iloc[0,9],
                            input_shape=(8,8,1), activation='relu',␣
 ↪padding='valid'))
    model.add(Convolution2D(filters = top10.iloc[0,1], kernel_size= top10.
 ↪iloc[0,9], padding='valid'))
    model.add(Convolution2D(filters = top10.iloc[0,1], kernel_size= top10.
 ↪iloc[0,9], padding='valid'))
    model.add(MaxPooling2D(pool_size=(2,2), padding='valid'))
    model.add(Dropout(0.3))
    model.add(Flatten())
    model.add(Dense(10, activation='softmax'))


es = EarlyStopping(monitor='val_accuracy', mode='max', verbose=0, patience=200)
mc = ModelCheckpoint('best_model', monitor='val_accuracy', mode='max',␣
 ↪verbose=0, save_best_only=True)
```

```
optimizer1 = optimizers.SGD(lr=top10.iloc[0,4], momentum=top10.iloc[0,5])
model.compile(optimizer=optimizer1, loss=top10.iloc[0,6], metrics=['accuracy'])
fit1 = model.fit(X_train,y_train, batch_size=top10.iloc[0,3], epochs=top10.iloc[0,2],
                 validation_data=(X_val,y_val), callbacks=[es, mc], verbose = 0)
fit = load_model('best_model')
end = time.time()
train_accuracy = fit.evaluate(X_train, y_train, verbose=0)
val_accuracy = fit.evaluate(X_val, y_val, verbose=0)
test_accuracy = fit.evaluate(X_test, y_test, verbose=0)
final_res = [end-start, train_accuracy[0], val_accuracy[0], test_accuracy[0],
                      train_accuracy[1], val_accuracy[1], test_accuracy[1]]

if top10.iloc[0,7] == 'Standardize':
    X_train11 = X_tr_std.reshape(-1, 8, 8, 1)
    X_test = X_test_std
    y_train11 = y_train1
else:
    X_train11 = X_tr_norm.reshape(-1, 8, 8, 1)
    X_test = X_test_norm
    y_train11 = y_train1

print("For hyper-parameters:\n",top10.iloc[0,:])
print("\n Time needed: %.2f" % (end-start))
scores = fit.evaluate(X_test, y_test, verbose=0)
print("\n Test Accuracy: %.2f%%" % (scores[1]*100))

A = fit.predict(X_train11)
cm = confusion_matrix(y_train11.argmax(axis=1), A.argmax(axis=1))
print("\n Train confusion matrix: \n", cm)
acc_train = np.diagonal(cm)/cm.sum(axis=1)
print("\n Class Accuracy for Training Data is:")
for i in range(10):
    print('Class %d: %.2f%%' %(i, acc_train[i]*100))

A = fit.predict(X_test)
cm = confusion_matrix(y_test.argmax(axis=1), A.argmax(axis=1))
print("\n Test confusion matrix: \n", cm)
acc_test = np.diagonal(cm)/cm.sum(axis=1)
print("\n Class Accuracy for Testing Data is:")
for i in range(10):
    print('Class %d: %.2f%%' %(i, acc_test[i]*100))
print("**********************************\n")
```

```
 Results For CNN
******************************************

For hyper-parameters:
 hidden_layers                                 3
filters                                       64
num_epochs                                   100
batch_size                                   128
learning_rate                                0.2
momentum                                     0.5
loss_func           categorical_crossentropy
data_scaling                       Standardize
activation_func                             relu
kernel_size                               (3, 3)
time                                     104.516
train_loss                           3.74972e-05
validation_loss                        0.0481159
test_loss                              0.0407299
train_acc                                      1
validation_acc                          0.992157
test_acc                                0.989983
Name: 509, dtype: object

 Time needed: 67.97

 Test Accuracy: 98.55%

 Train confusion matrix:
 [[376   0   0   0   0   0   0   0   0   0]
 [  0 389   0   0   0   0   0   0   0   0]
 [  0   0 380   0   0   0   0   0   0   0]
 [  0   0   0 388   0   0   0   0   0   1]
 [  0   0   0   0 386   0   1   0   0   0]
 [  0   0   0   0   0 376   0   0   0   0]
 [  0   0   0   0   0   0 377   0   0   0]
 [  0   0   0   1   0   0   0 386   0   0]
 [  0   1   0   0   0   0   0   0 378   1]
 [  0   0   0   0   0   0   0   0   0 382]]

 Class Accuracy for Training Data is:
Class 0: 100.00%
Class 1: 100.00%
Class 2: 100.00%
Class 3: 99.74%
Class 4: 99.74%
Class 5: 100.00%
Class 6: 100.00%
Class 7: 99.74%
```

```
Class 8: 99.47%
Class 9: 100.00%

 Test confusion matrix:
 [[177   0   0   0   1   0   0   0   0   0]
 [  0 182   0   0   0   0   0   0   0   0]
 [  0   1 176   0   0   0   0   0   0   0]
 [  0   0   0 180   0   1   0   0   0   2]
 [  0   2   0   0 179   0   0   0   0   0]
 [  0   0   0   0   1 177   1   0   0   3]
 [  0   0   0   0   2   1 178   0   0   0]
 [  0   0   0   0   0   0   0 177   0   2]
 [  0   1   0   1   1   0   0   0 170   1]
 [  0   0   0   1   1   1   0   0   2 175]]

 Class Accuracy for Testing Data is:
Class 0: 99.44%
Class 1: 100.00%
Class 2: 99.44%
Class 3: 98.36%
Class 4: 98.90%
Class 5: 97.25%
Class 6: 98.34%
Class 7: 98.88%
Class 8: 97.70%
Class 9: 97.22%
**********************************
```

Based on the time distribution, CNN takes longer time than fully connected feed-forward networks. However, the time distribution for CNN is less skewed than fully connected feed-forward networks.

Based on test accuracy distributions, overall accuracy for test data using CNN is higher (about 98%) than the fully connected feed-forward networks and the variance is also lower for these hyper-parameter combinations.

It is found that using CNN with 3 hidden layers, 64 units, number of epochs 100, batch size 128, learning rate 0.2, momentum 0.5 and kernel size (3,3) has the highest test accuracy (about 98.00%) which is higher than the fully connected feed forward networks. Note that, this model was fitted based on only 1-fold cross validation with no repeated sample. It might be different if we use repeated k fold cross validation.

Training accuracy for all classes are almost 100%. However, test accuracy for all classes are around 98%. Class 0 and 1 have the highest test accuracy (about 100%) and class 8 has the lowest accuracy (about 97%) which is much higher than the fully connected feed forward networks. Overall classification accuracy, class accuracy, and confusion matrix for both training and testing data are given in above tables.

1.1 Important References:

1. https://towardsdatascience.com/building-our-first-neural-network-in-keras-bdc8abbc17f5
2. https://towardsdatascience.com/building-a-deep-learning-model-using-keras-1548ca149d37
3. https://machinelearningmastery.com/tutorial-first-neural-network-python-keras/
4. https://towardsdatascience.com/building-a-convolutional-neural-network-cnn-in-keras-329fbbadc5f5
5. https://towardsdatascience.com/convolutional-neural-networks-for-beginners-practical-guide-with-python-and-keras-dc688ea90dca

[ ]:

```

```