1. Introduction

In this article, the emotion distribution learning to determine the emotion distribution for the given images is proposed. Here a current state-of-the-art algorithm model which have the distribution specific loss is considered as a reference and proper modelling of the correlation for the image emotion distribution learning is added as the additional feature. For a particular image, the emotion recognized will vary when the model used in it varies. So here the graph convolutional network is used for capturing the hidden relationship in the graph data which will be formed by converting each pixel into the graph with equivalent number of nodes. This emotion correlation matrix represents the probability distribution of the particular emotion from which any test data can be recognized.

In [48]:

```
import warnings
warnings.filterwarnings('ignore')
import numpy as np
import matplotlib.pyplot as plt
import os
import cv2 as cv
import random
from sklearn.preprocessing import LabelEncoder
import glob
import time
import pickle
import pandas as pd
from pathlib import Path
from keras.preprocessing.image import img_to_array
from sklearn.preprocessing import LabelBinarizer
from sklearn.model_selection import train_test_split
import tensorflow as tf
import keras.backend as K
from keras.layers import Input, Dense, Flatten
from keras.models import Model
from keras.callbacks import EarlyStopping
from keras.regularizers import l2
from sklearn.model_selection import train_test_split
from spektral.layers import GraphConv, GlobalAvgPool, EdgeConditionedConv
from spektral.utils import Batch, batch_iterator
from spektral.utils import label_to_one_hot, normalized_laplacian
from spektral.layers.ops import sp_matrix_to_sp_tensor
import graph
import networkx as nx
import scipy.sparse as sp
from spektral.datasets import mnist
from keras.layers import MaxPooling2D, Reshape
from spektral.layers import GraphConv, ChebConv
from spektral.utils import localpooling_filter
from tensorflow.keras.optimizers import Adam
from sklearn import metrics
import matplotlib.pyplot as plt
import seaborn as sns
import pandas as pd
from utilities import generate_graph,create_graph
```

In [49]:

```
train_path = 'C:\\Users\\ACER\\Desktop\\Emotion_detection\\train_trim'
# Parameters
user_reguralization_rate = 5e-4
user_model_learning_rate = 0.03
user_model_batch = 32
epochs = 80
print(train_path)
```

```
C:\Users\ACER\Desktop\Emotion_detection\train_trim
```

In [50]:

```
# folder preprocessing

def check_folder_path(path):
    if not Path.is_dir(path):
        raise ValueError("argument is not directory")

    yield from filter(Path.is_dir, path.iterdir())


def check_depth(path, depth):
    if 0 > depth:
        raise ValueError("depth smaller 0")
    if 0 == depth:
        yield from check_folder_path(path)
    else:
        for folder in check_folder_path(path):
            yield from check_depth(folder, depth - 1)


def check_files(path):
    if not Path.is_dir(path):
        raise ValueError("argument is not a directory")
    yield from filter(Path.is_file, path.iterdir())


def sum_file_size(filepaths):
    return sum([filep.stat().st_size for filep in filepaths])


def convert_image_to_array(image_dir):
    try:
        image = cv.imread(image_dir)

        if image is not None:

            image1 = cv.resize(image, default_image_size)
            gray = cv.cvtColor(image1, cv.COLOR_BGR2GRAY)

            return img_to_array(gray).flatten()
        else:
            return np.array([])
    except Exception as e:
        print(f"Error : {e}")
        return None

def graph_convolution_one_layer_model(A, N=28 * 28, F=1,n_out=10,l2_reg=user_reguraliza
tion_rate,
                     learning_rate=user_model_learning_rate,
                     ):
    """
    Creating a simple single layer GCN
    """

    L = localpooling_filter(A)

    X_in = Input(shape=(N, F)) # N=nodes and F=features dimension

    A_in = Input(tensor=sp_matrix_to_sp_tensor(L))
```

```
    graph_conv = GraphConv(10,
                           activation='relu',
                           kernel_regularizer=l2(l2_reg),
                           use_bias=True)([X_in, A_in])

    fc = Flatten()(graph_conv)
    output = Dense(n_out, activation='softmax')(fc)

    # Build model
    model = Model(inputs=[X_in, A_in], outputs=output)
    model.compile(optimizer='adam', loss='sparse_categorical_crossentropy', metrics=['a
ccuracy'])
    return model

def graph_convolution_network(A, N=28 * 28, F=1,
        n_out=10,
        l2_reg=user_reguralization_rate,
        learning_rate=user_model_learning_rate,
        ):
    """
    Creating two layer GCN
    """

    L = localpooling_filter(A)
    X_in = Input(shape=(N, F))
    A_in = Input(tensor=sp_matrix_to_sp_tensor(L))

    graph_conv = GraphConv(32,
                           activation='relu',
                           kernel_regularizer=l2(l2_reg),
                           use_bias=True)([X_in, A_in])
    graph_conv = GraphConv(32,
                           activation='relu',
                           kernel_regularizer=l2(l2_reg),
                           use_bias=True)([graph_conv, A_in])

    rs = Reshape((28, 28, 32))(graph_conv)
    pooled = MaxPooling2D(pool_size=(2, 2))(rs)
    flatten = Flatten()(pooled)
    fc = Dense(512, activation='relu')(flatten)
    output = Dense(n_out, activation='softmax')(fc)
    # Build model
    model = Model(inputs=[X_in, A_in], outputs=output)
    model.compile(optimizer='adam', loss='sparse_categorical_crossentropy', metrics=['a
ccuracy'])

    return model
```

In [51]:

```
image_list, label_list = [], []
train_labels = os.listdir(train_path)  # take training path labels
num_labels=len(train_labels)
print(num_labels)
train_labels.sort()  # sort the labels
print(train_labels)  # primt the lables
labels = []  # create label variables so as to decode text to number
total = 0  # initialize
tot_file = []  # initialize
count = 1  # start count to check number of images
i = 0
j = 0
k = 0
print(Path.cwd())  # gives the current path
for folder in check_depth(Path.cwd(), 1):
    # first loop will pick the first foldend then next folder
    files = list(check_files(folder))  # list all files in folder
    file = len(files)  # length of files
    tot_file.append(file)  # because we are running for all folder
    # we are appending all files in tot_file at the end we
    # shall get the list of number of files in the folder
    # we are doing this because every folder has different number of files
    # at the end when we are trainig all class of disease have to be
    # trained equally, hence find the least number of images in the folder
    # and then train accordingly
    total_size = sum_file_size(files)
    # total size of files
    count = count + 1  # check total number of files executed
    print(f'{folder}:filecount:{len(files)},total size:{total_size}')

tot_file.sort()  # sort files based on ascending order
num = int(tot_file[1])  # Index 0 is junkhence extract index 1

print('tOTAL FILE:', tot_file)
print(num)

images_per_class = 3200 # consider number of images per class
# %%START WITH TRAINING
# for tr_name in range(0,2):
count = 0
default_image_size = tuple((28, 28))

for count in range(0, len(train_labels)):

    tr_name = count

    dir = train_path + '\\' + train_labels[tr_name]
#     print(dir)
    current_label = train_labels[tr_name]
    print("[STATUS] processed folder: {}".format(current_label))
    k = 1
    file_sub_folder = os.listdir(dir)
#     print(file_sub_folder)
    for x in range(0, images_per_class):
        file = dir + '\\' + file_sub_folder[x]
#         print(file)
        image_list.append(convert_image_to_array(file))
        label_list.append(current_label)
        i += 1
```

```
        k += 1
        count = count + 1
print("[STATUS] training labels{}".format(np.array(label_list).shape))
labelEncoder = LabelEncoder()
image_size = len(image_list)
image_labels = labelEncoder.fit_transform(label_list)

np_image_list = np.array(image_list, dtype=np.float32) / 225.0
print("[INFO] Spliting data to train, test")
X_train, X_test, y_train, y_test = train_test_split(np_image_list, image_labels, test_s
ize=0.2, random_state=42)
X_val = X_test
y_val = y_test
```

```
4
['angry', 'happy', 'sad', 'surprise']
C:\Users\ACER\Desktop\Emotion_detection
C:\Users\ACER\Desktop\Emotion_detection\.idea\inspectionProfiles:filecoun
t:1,total size:174
C:\Users\ACER\Desktop\Emotion_detection\gcn1\conda-meta:filecount:61,total
size:11459445
C:\Users\ACER\Desktop\Emotion_detection\gcn1\DLLs:filecount:34,total size:
10595549
C:\Users\ACER\Desktop\Emotion_detection\gcn1\include:filecount:102,total s
ize:656144
C:\Users\ACER\Desktop\Emotion_detection\gcn1\Lib:filecount:172,total size:
4325196
C:\Users\ACER\Desktop\Emotion_detection\gcn1\Library:filecount:0,total siz
e:0
C:\Users\ACER\Desktop\Emotion_detection\gcn1\libs:filecount:3,total size:5
12288
C:\Users\ACER\Desktop\Emotion_detection\gcn1\Scripts:filecount:83,total si
ze:13221247
C:\Users\ACER\Desktop\Emotion_detection\gcn1\share:filecount:0,total size:
0
C:\Users\ACER\Desktop\Emotion_detection\gcn1\sip:filecount:0,total size:0
C:\Users\ACER\Desktop\Emotion_detection\gcn1\tcl:filecount:6,total size:16
00642
C:\Users\ACER\Desktop\Emotion_detection\gcn1\Tools:filecount:0,total size:
0
C:\Users\ACER\Desktop\Emotion_detection\train\angry:filecount:3993,total s
ize:6332643
C:\Users\ACER\Desktop\Emotion_detection\train\happy:filecount:7164,total s
ize:11296707
C:\Users\ACER\Desktop\Emotion_detection\train\neutral:filecount:4982,total
size:7740763
C:\Users\ACER\Desktop\Emotion_detection\train\sad:filecount:4938,total siz
e:7640144
C:\Users\ACER\Desktop\Emotion_detection\train\surprise:filecount:3205,tota
l size:5182401
C:\Users\ACER\Desktop\Emotion_detection\train_trim\angry:filecount:3993,to
tal size:6332643
C:\Users\ACER\Desktop\Emotion_detection\train_trim\happy:filecount:7164,to
tal size:11296707
C:\Users\ACER\Desktop\Emotion_detection\train_trim\sad:filecount:4938,tota
l size:7640144
C:\Users\ACER\Desktop\Emotion_detection\train_trim\surprise:filecount:320
5,total size:5182401
tOTAL FILE: [0, 0, 0, 0, 1, 3, 6, 34, 61, 83, 102, 172, 3205, 3205, 3993,
3993, 4938, 4938, 4982, 7164, 7164]
0
[STATUS] processed folder: angry
[STATUS] processed folder: happy
[STATUS] processed folder: sad
[STATUS] processed folder: surprise
[STATUS] training labels(12800,)
[INFO] Spliting data to train, test
```

In [52]:

```
gen_random_seed = 2000
os.environ['PYTHONHASHSEED']=str(gen_random_seed)
random.seed(gen_random_seed)
np.random.seed(gen_random_seed)
tf.compat.v1.random.set_random_seed(gen_random_seed)

session_conf = tf.compat.v1.ConfigProto(intra_op_parallelism_threads=1, inter_op_parall
elism_threads=1)
sess = tf.compat.v1.Session(graph=tf.compat.v1.get_default_graph(), config=session_conf
)
K.set_session(sess)
```

Splitting the dataset

In [53]:

```
X_train, X_val, X_test = X_train[..., None], X_val[..., None], X_test[..., None]
N = X_train.shape[-2]      # Number of nodes in the graphs
F = X_train.shape[-1]      # Node features dimensionality
n_out = 10  # Dimension of the target
print(X_train.shape, y_train.shape)
print(X_val.shape, y_val.shape)
print(X_test.shape, y_test.shape)
```

```
(10240, 784, 1) (10240,)
(2560, 784, 1) (2560,)
(2560, 784, 1) (2560,)
```

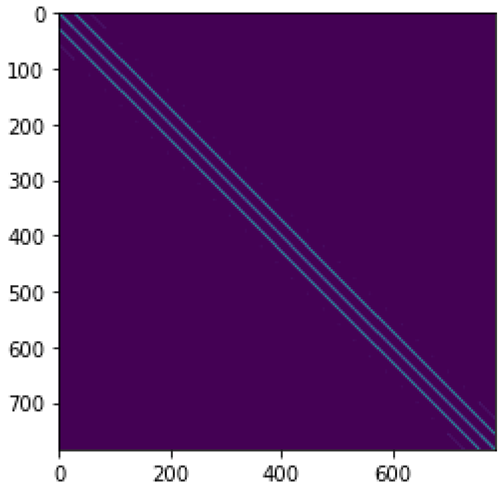
Creating graph with same dimension of images

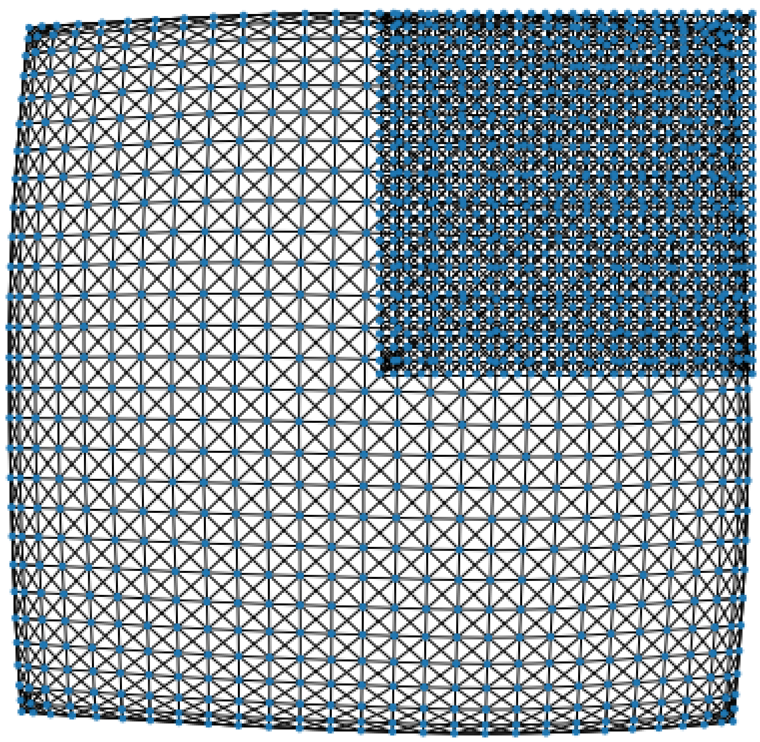
1. Create a grid the same orientation as the training picture.
2. Find the embedding of the grid.
3. Generate the compressed sparse row (CSR) matrix.
4. Create two graph object with the CSR matrix. One is a complete graph and another one is after removing all the nodes without edges.
5. Find the degree matrix for the graph and repeat the steps for that matrix.

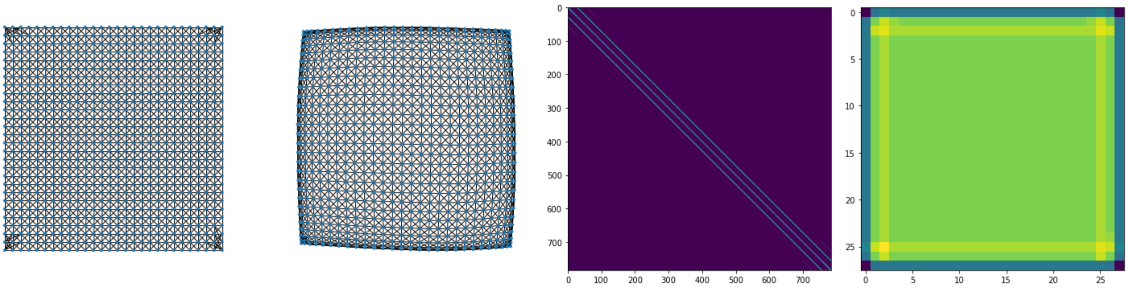
In [54]:

```
A = generate_graph(28, 8)
plt.imshow(A.todense())
fig, ax = plt.subplots(figsize=(8, 8))
ax = create_graph(A, ax=ax, size_factor=1)
ax = create_graph(A, ax=ax, size_factor=1, spring_layout=True)
fig, axes = plt.subplots(figsize=(20, 5), ncols=4)
axes[2].imshow(A.todense())

# degree matrix D
D = A.sum(axis=0).reshape(28, 28)
axes[3].imshow(D)

axes[0] = create_graph(A, ax=axes[0], size_factor=1)
axes[1] = create_graph(A, ax=axes[1], size_factor=1, spring_layout=True)
fig.tight_layout()

threshold = 0.25  # to reduce the noise for averaged signals
# threshold = 0.5
d_emotion_graphs = {}  # to collect feature graphs from each class
```

```
3198 > 3136 edges
Number of nodes: 784; Number of edges: 3198
Number of nodes: 784; Number of edges: 3198
After removing nodes without edges:
Number of nodes: 784; Number of edges: 3198
Number of nodes: 784; Number of edges: 3198
Number of nodes: 784; Number of edges: 3198
After removing nodes without edges:
Number of nodes: 784; Number of edges: 3198
```





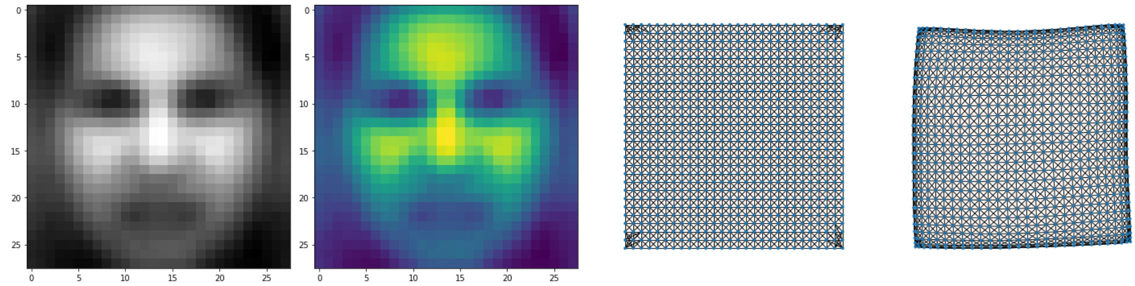


Creating sample graphs for each class of emotions

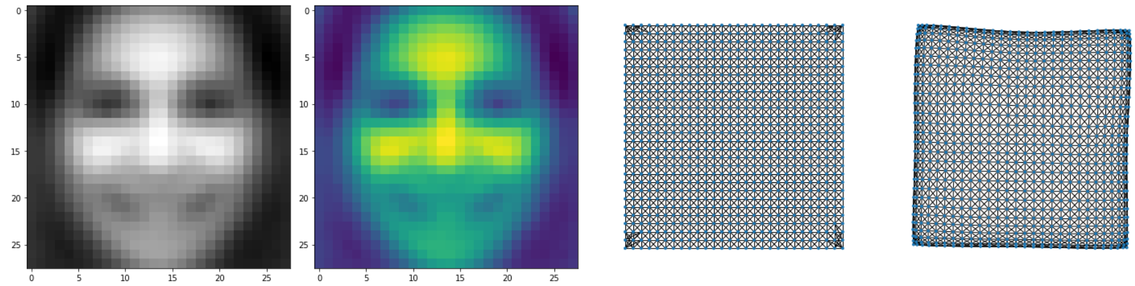
In [55]:

```
for i in range(num_labels):
    mask = y_train == i
    fig, axes = plt.subplots(figsize=(20, 5), ncols=4)
    x_train_i_avg = X_train[mask].mean(axis=0).flatten()
    axes[0].imshow(x_train_i_avg.reshape(28, 28),cmap='gray')
    # threshold the averages of pixels
    x_train_i_avg[x_train_i_avg < threshold] = 0
    axes[1].imshow(x_train_i_avg.reshape(28, 28))
    # a sparse diag matrix with the intensities values on the diagnoal
    A_diag_i = sp.diags(x_train_i_avg, dtype=np.float32).tolil()
    A_i = A.dot(A_diag_i)
    d_emotion_graphs[i] = A_i
    axes[2] = create_graph(A_i, ax=axes[2], size_factor=1)
    axes[3] = create_graph(A_i, ax=axes[3], size_factor=1, spring_layout=True)
    fig.tight_layout()
    plt.show()
```

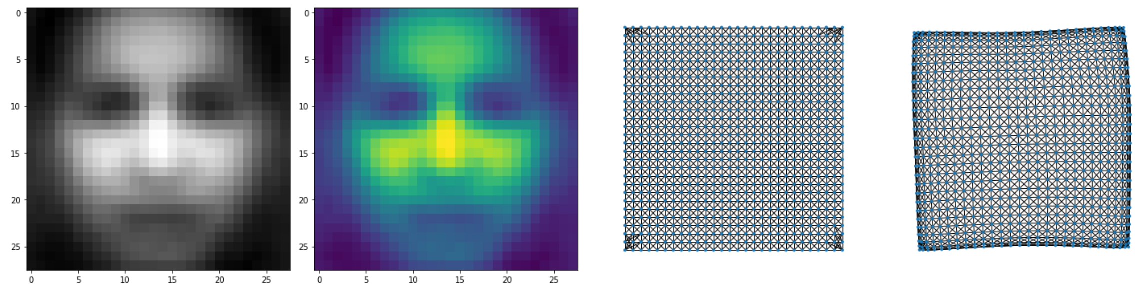
```
Number of nodes: 784; Number of edges: 3198
Number of nodes: 784; Number of edges: 3198
After removing nodes without edges:
Number of nodes: 784; Number of edges: 3198
```



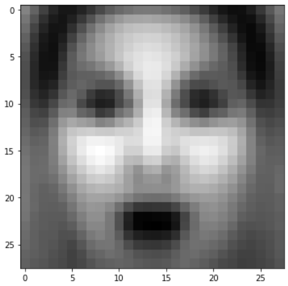
```
Number of nodes: 784; Number of edges: 3198
Number of nodes: 784; Number of edges: 3198
After removing nodes without edges:
Number of nodes: 784; Number of edges: 3198
```

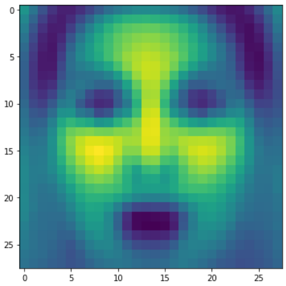


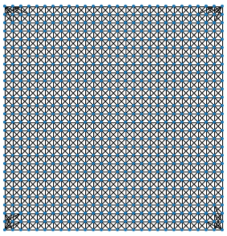
```
Number of nodes: 784; Number of edges: 3198
Number of nodes: 784; Number of edges: 3198
After removing nodes without edges:
Number of nodes: 784; Number of edges: 3198
```



```
Number of nodes: 784; Number of edges: 3198
Number of nodes: 784; Number of edges: 3198
After removing nodes without edges:
Number of nodes: 784; Number of edges: 3198
```








Training the data with single layer GCN

In [56]:

```
# --------------graph_convolution_one_layer_model-----------
print("=========== -graph_convolution_one_layer_model- ============")
test_scores = []
model_full_grid = graph_convolution_one_layer_model(A)
model_full_grid.summary()
validation_data = (X_val, y_val)
model_full_grid.fit(X_train,
                    y_train,
                    batch_size=user_model_batch,
                    validation_data=validation_data,
                    epochs=epochs)
print('Evaluating model.')
eval_results = model_full_grid.evaluate(X_test,
                              y_test,
                              batch_size=user_model_batch)
print('loss:{}\n'
      'acc: {}'.format(*eval_results))

test_scores.append({
    'model': 'graph_convolution_one_layer_model',
    'accuracy': eval_results[1]
})
```

```
=========== -graph_convolution_one_layer_model- ============
Model: "model_12"
__________________________________________________________________________
________________________
Layer (type)                    Output Shape         Param #     Connected
to
==========================================================================
========================
input_22 (InputLayer)           (None, 784, 1)       0
__________________________________________________________________________
________________________
input_23 (InputLayer)           (784, 784)           0
__________________________________________________________________________
________________________
graph_conv_13 (GraphConv)       (None, 784, 10)      20          input_22
[0][0]
                                                                 input_23
[0][0]
__________________________________________________________________________
________________________
flatten_12 (Flatten)            (None, 7840)         0           graph_con
v_13[0][0]
__________________________________________________________________________
________________________
dense_15 (Dense)                (None, 10)           78410       flatten_1
2[0][0]
==========================================================================
========================
Total params: 78,430
Trainable params: 78,430
Non-trainable params: 0
__________________________________________________________________________
________________________
Train on 10240 samples, validate on 2560 samples
Epoch 1/80
10240/10240 [==============================] - 7s 658us/step - loss: 1.338
2 - acc: 0.3693 - val_loss: 1.2959 - val_acc: 0.4266
Epoch 2/80
10240/10240 [==============================] - 5s 487us/step - loss: 1.235
4 - acc: 0.4430 - val_loss: 1.2214 - val_acc: 0.4426
Epoch 3/80
10240/10240 [==============================] - 5s 481us/step - loss: 1.206
2 - acc: 0.4634 - val_loss: 1.2131 - val_acc: 0.4547
Epoch 4/80
10240/10240 [==============================] - 5s 505us/step - loss: 1.191
4 - acc: 0.4741 - val_loss: 1.2009 - val_acc: 0.4609
Epoch 5/80
10240/10240 [==============================] - 5s 480us/step - loss: 1.180
1 - acc: 0.4820 - val_loss: 1.2123 - val_acc: 0.4602
Epoch 6/80
10240/10240 [==============================] - 5s 482us/step - loss: 1.171
4 - acc: 0.4891 - val_loss: 1.2144 - val_acc: 0.45781.1752 - ETA: 0s - los
s: 1.1725 - acc
Epoch 7/80
10240/10240 [==============================] - 5s 506us/step - loss: 1.163
7 - acc: 0.4921 - val_loss: 1.1944 - val_acc: 0.4723
Epoch 8/80
10240/10240 [==============================] - 5s 482us/step - loss: 1.156
8 - acc: 0.4989 - val_loss: 1.1896 - val_acc: 0.4766
Epoch 9/80
10240/10240 [==============================] - 5s 480us/step - loss: 1.151
```

```
9 - acc: 0.5040 - val_loss: 1.2080 - val_acc: 0.4570
Epoch 10/80
10240/10240 [==============================] - 5s 493us/step - loss: 1.149
1 - acc: 0.4993 - val_loss: 1.1806 - val_acc: 0.4836
Epoch 11/80
10240/10240 [==============================] - 5s 490us/step - loss: 1.143
8 - acc: 0.5064 - val_loss: 1.2008 - val_acc: 0.4668
Epoch 12/80
10240/10240 [==============================] - 5s 480us/step - loss: 1.137
6 - acc: 0.5110 - val_loss: 1.1724 - val_acc: 0.4832
Epoch 13/80
10240/10240 [==============================] - 5s 482us/step - loss: 1.131
0 - acc: 0.5141 - val_loss: 1.1739 - val_acc: 0.4781
Epoch 14/80
10240/10240 [==============================] - 5s 506us/step - loss: 1.132
9 - acc: 0.5084 - val_loss: 1.1723 - val_acc: 0.4934
Epoch 15/80
10240/10240 [==============================] - 5s 481us/step - loss: 1.122
9 - acc: 0.5157 - val_loss: 1.2045 - val_acc: 0.4688
Epoch 16/80
10240/10240 [==============================] - 5s 480us/step - loss: 1.119
5 - acc: 0.5149 - val_loss: 1.1822 - val_acc: 0.4754
Epoch 17/80
10240/10240 [==============================] - 5s 504us/step - loss: 1.118
7 - acc: 0.5169 - val_loss: 1.1701 - val_acc: 0.4855
Epoch 18/80
10240/10240 [==============================] - 5s 482us/step - loss: 1.113
3 - acc: 0.5257 - val_loss: 1.1968 - val_acc: 0.4777
Epoch 19/80
10240/10240 [==============================] - 5s 482us/step - loss: 1.111
0 - acc: 0.5225 - val_loss: 1.1755 - val_acc: 0.4891
Epoch 20/80
10240/10240 [==============================] - 5s 518us/step - loss: 1.110
3 - acc: 0.5243 - val_loss: 1.1644 - val_acc: 0.4969
Epoch 21/80
10240/10240 [==============================] - 5s 481us/step - loss: 1.105
8 - acc: 0.5259 - val_loss: 1.1764 - val_acc: 0.4793
Epoch 22/80
10240/10240 [==============================] - 5s 482us/step - loss: 1.104
1 - acc: 0.5309 - val_loss: 1.1884 - val_acc: 0.4809
Epoch 23/80
10240/10240 [==============================] - 5s 509us/step - loss: 1.101
7 - acc: 0.5265 - val_loss: 1.1813 - val_acc: 0.4879
Epoch 24/80
10240/10240 [==============================] - 5s 492us/step - loss: 1.095
6 - acc: 0.5352 - val_loss: 1.1873 - val_acc: 0.4852
Epoch 25/80
10240/10240 [==============================] - 5s 499us/step - loss: 1.096
0 - acc: 0.5278 - val_loss: 1.1776 - val_acc: 0.4828
Epoch 26/80
10240/10240 [==============================] - 5s 504us/step - loss: 1.091
0 - acc: 0.5339 - val_loss: 1.1764 - val_acc: 0.4859
Epoch 27/80
10240/10240 [==============================] - 5s 480us/step - loss: 1.091
8 - acc: 0.5353 - val_loss: 1.1928 - val_acc: 0.4723
Epoch 28/80
10240/10240 [==============================] - 5s 483us/step - loss: 1.088
0 - acc: 0.5434 - val_loss: 1.1925 - val_acc: 0.4852
Epoch 29/80
10240/10240 [==============================] - 5s 486us/step - loss: 1.082
6 - acc: 0.5389 - val_loss: 1.1851 - val_acc: 0.4793
```

```
Epoch 30/80
10240/10240 [==============================] - 5s 508us/step - loss: 1.083
2 - acc: 0.5455 - val_loss: 1.1719 - val_acc: 0.4852
Epoch 31/80
10240/10240 [==============================] - 5s 485us/step - loss: 1.078
6 - acc: 0.5423 - val_loss: 1.1840 - val_acc: 0.4844
Epoch 32/80
10240/10240 [==============================] - 5s 498us/step - loss: 1.079
6 - acc: 0.5427 - val_loss: 1.2289 - val_acc: 0.4605
Epoch 33/80
10240/10240 [==============================] - 5s 517us/step - loss: 1.074
8 - acc: 0.5485 - val_loss: 1.1965 - val_acc: 0.4777
Epoch 34/80
10240/10240 [==============================] - 5s 481us/step - loss: 1.073
0 - acc: 0.5485 - val_loss: 1.2115 - val_acc: 0.4695
Epoch 35/80
10240/10240 [==============================] - 5s 485us/step - loss: 1.069
4 - acc: 0.5481 - val_loss: 1.1795 - val_acc: 0.4754
Epoch 36/80
10240/10240 [==============================] - 5s 508us/step - loss: 1.069
4 - acc: 0.5481 - val_loss: 1.1782 - val_acc: 0.4895
Epoch 37/80
10240/10240 [==============================] - 5s 484us/step - loss: 1.065
6 - acc: 0.5521 - val_loss: 1.2112 - val_acc: 0.4734
Epoch 38/80
10240/10240 [==============================] - 5s 487us/step - loss: 1.068
7 - acc: 0.5491 - val_loss: 1.2076 - val_acc: 0.4793
Epoch 39/80
10240/10240 [==============================] - 5s 511us/step - loss: 1.061
7 - acc: 0.5502 - val_loss: 1.1824 - val_acc: 0.4809
Epoch 40/80
10240/10240 [==============================] - 5s 485us/step - loss: 1.057
4 - acc: 0.5589 - val_loss: 1.1873 - val_acc: 0.4813
Epoch 41/80
10240/10240 [==============================] - 5s 487us/step - loss: 1.060
1 - acc: 0.5551 - val_loss: 1.2026 - val_acc: 0.4852
Epoch 42/80
10240/10240 [==============================] - 5s 508us/step - loss: 1.057
7 - acc: 0.5613 - val_loss: 1.2087 - val_acc: 0.4813
Epoch 43/80
10240/10240 [==============================] - 5s 475us/step - loss: 1.054
1 - acc: 0.5550 - val_loss: 1.2014 - val_acc: 0.4793
Epoch 44/80
10240/10240 [==============================] - 5s 490us/step - loss: 1.056
0 - acc: 0.5598 - val_loss: 1.1908 - val_acc: 0.4859
Epoch 45/80
10240/10240 [==============================] - 5s 526us/step - loss: 1.053
6 - acc: 0.5601 - val_loss: 1.1990 - val_acc: 0.4816
Epoch 46/80
10240/10240 [==============================] - 5s 501us/step - loss: 1.054
7 - acc: 0.5568 - val_loss: 1.1854 - val_acc: 0.4906
Epoch 47/80
10240/10240 [==============================] - 5s 473us/step - loss: 1.046
2 - acc: 0.5637 - val_loss: 1.1897 - val_acc: 0.4793
Epoch 48/80
10240/10240 [==============================] - 5s 477us/step - loss: 1.045
8 - acc: 0.5644 - val_loss: 1.2327 - val_acc: 0.4727
Epoch 49/80
10240/10240 [==============================] - 5s 495us/step - loss: 1.046
0 - acc: 0.5649 - val_loss: 1.2093 - val_acc: 0.4789
Epoch 50/80
```

```
10240/10240 [==============================] - 5s 475us/step - loss: 1.046
1 - acc: 0.5586 - val_loss: 1.1936 - val_acc: 0.4820
Epoch 51/80
10240/10240 [==============================] - 5s 474us/step - loss: 1.042
8 - acc: 0.5631 - val_loss: 1.1947 - val_acc: 0.4832
Epoch 52/80
10240/10240 [==============================] - 5s 501us/step - loss: 1.041
9 - acc: 0.5655 - val_loss: 1.2188 - val_acc: 0.4859
Epoch 53/80
10240/10240 [==============================] - 5s 474us/step - loss: 1.037
7 - acc: 0.5697 - val_loss: 1.1966 - val_acc: 0.4867
Epoch 54/80
10240/10240 [==============================] - 5s 472us/step - loss: 1.044
6 - acc: 0.5643 - val_loss: 1.2030 - val_acc: 0.4805
Epoch 55/80
10240/10240 [==============================] - 5s 492us/step - loss: 1.035
6 - acc: 0.5685 - val_loss: 1.2075 - val_acc: 0.4785
Epoch 56/80
10240/10240 [==============================] - 5s 473us/step - loss: 1.032
8 - acc: 0.5682 - val_loss: 1.1943 - val_acc: 0.4797
Epoch 57/80
10240/10240 [==============================] - 5s 472us/step - loss: 1.036
9 - acc: 0.5643 - val_loss: 1.2084 - val_acc: 0.4813
Epoch 58/80
10240/10240 [==============================] - 5s 498us/step - loss: 1.033
0 - acc: 0.5753 - val_loss: 1.2129 - val_acc: 0.4750
Epoch 59/80
10240/10240 [==============================] - 5s 506us/step - loss: 1.034
7 - acc: 0.5675 - val_loss: 1.2397 - val_acc: 0.4688
Epoch 60/80
10240/10240 [==============================] - 5s 484us/step - loss: 1.028
9 - acc: 0.5753 - val_loss: 1.2202 - val_acc: 0.4867
Epoch 61/80
10240/10240 [==============================] - 5s 497us/step - loss: 1.027
1 - acc: 0.5712 - val_loss: 1.2081 - val_acc: 0.4828
Epoch 62/80
10240/10240 [==============================] - 5s 486us/step - loss: 1.029
9 - acc: 0.5726 - val_loss: 1.2089 - val_acc: 0.4875
Epoch 63/80
10240/10240 [==============================] - 5s 474us/step - loss: 1.026
9 - acc: 0.5736 - val_loss: 1.2152 - val_acc: 0.4781
Epoch 64/80
10240/10240 [==============================] - 5s 472us/step - loss: 1.026
4 - acc: 0.5762 - val_loss: 1.2052 - val_acc: 0.4832
Epoch 65/80
10240/10240 [==============================] - 5s 496us/step - loss: 1.020
7 - acc: 0.5809 - val_loss: 1.2648 - val_acc: 0.4617
Epoch 66/80
10240/10240 [==============================] - 5s 472us/step - loss: 1.023
4 - acc: 0.5794 - val_loss: 1.2048 - val_acc: 0.4871
Epoch 67/80
10240/10240 [==============================] - 5s 472us/step - loss: 1.021
3 - acc: 0.5775 - val_loss: 1.2313 - val_acc: 0.4766
Epoch 68/80
10240/10240 [==============================] - 5s 512us/step - loss: 1.019
6 - acc: 0.5833 - val_loss: 1.2150 - val_acc: 0.4801
Epoch 69/80
10240/10240 [==============================] - 5s 474us/step - loss: 1.017
3 - acc: 0.5805 - val_loss: 1.2071 - val_acc: 0.4965
Epoch 70/80
10240/10240 [==============================] - 5s 473us/step - loss: 1.018
```

```
5 - acc: 0.5800 - val_loss: 1.2189 - val_acc: 0.4801
Epoch 71/80
10240/10240 [==============================] - 5s 495us/step - loss: 1.014
4 - acc: 0.5810 - val_loss: 1.2051 - val_acc: 0.4879
Epoch 72/80
10240/10240 [==============================] - 5s 474us/step - loss: 1.014
2 - acc: 0.5819 - val_loss: 1.2326 - val_acc: 0.4805
Epoch 73/80
10240/10240 [==============================] - 5s 474us/step - loss: 1.011
1 - acc: 0.5842 - val_loss: 1.2444 - val_acc: 0.4840
Epoch 74/80
10240/10240 [==============================] - 5s 490us/step - loss: 1.012
1 - acc: 0.5856 - val_loss: 1.2140 - val_acc: 0.4891
Epoch 75/80
10240/10240 [==============================] - 5s 476us/step - loss: 1.013
8 - acc: 0.5859 - val_loss: 1.2213 - val_acc: 0.4883
Epoch 76/80
10240/10240 [==============================] - 5s 473us/step - loss: 1.008
5 - acc: 0.5843 - val_loss: 1.2068 - val_acc: 0.4848
Epoch 77/80
10240/10240 [==============================] - 5s 474us/step - loss: 1.007
2 - acc: 0.5849 - val_loss: 1.2134 - val_acc: 0.4895
Epoch 78/80
10240/10240 [==============================] - 5s 500us/step - loss: 1.007
3 - acc: 0.5909 - val_loss: 1.2080 - val_acc: 0.4887
Epoch 79/80
10240/10240 [==============================] - 5s 475us/step - loss: 1.005
9 - acc: 0.5889 - val_loss: 1.2220 - val_acc: 0.4723
Epoch 80/80
10240/10240 [==============================] - 5s 474us/step - loss: 1.000
3 - acc: 0.5886 - val_loss: 1.2392 - val_acc: 0.4805
Evaluating model.
2560/2560 [==============================] - 0s 183us/step
loss:1.2392246305942536
acc: 0.48046875
```

Training the data with multi layer GCN

In [57]:

```
# --------------graph_convolution_multi_layer_model-----------
print("=========== -graph_convolution_multi_layer_model- ============")
test_scores = []
model_full_grid = graph_convolution_network(A)
model_full_grid.summary()
validation_data = (X_val, y_val)
model_full_grid.fit(X_train,
                    y_train,
                    batch_size=user_model_batch,
                    validation_data=validation_data,
                    epochs=epochs)
print('Evaluating model.')
eval_results = model_full_grid.evaluate(X_test,
                              y_test,
                              batch_size=user_model_batch)
print('loss:{}\n'
      'acc: {}'.format(*eval_results))

test_scores.append({
    'model': 'graph_convolution_multi_layer_model',
    'accuracy': eval_results[1]
})
```

```
=========== -graph_convolution_multi_layer_model- ============
Model: "model_13"
________________________________________________________________________
__________________________
Layer (type)                    Output Shape         Param #     Connect
ed to
========================================================================
==========================
input_24 (InputLayer)           (None, 784, 1)       0
________________________________________________________________________
__________________________
input_25 (InputLayer)           (784, 784)           0
________________________________________________________________________
__________________________
graph_conv_14 (GraphConv)       (None, 784, 32)      64          input_2
4[0][0]
                                                                 input_2
5[0][0]
________________________________________________________________________
__________________________
graph_conv_15 (GraphConv)       (None, 784, 32)      1056        graph_c
onv_14[0][0]
                                                                 input_2
5[0][0]
________________________________________________________________________
__________________________
reshape_3 (Reshape)             (None, 28, 28, 32)   0           graph_c
onv_15[0][0]
________________________________________________________________________
__________________________
max_pooling2d_3 (MaxPooling2D)  (None, 14, 14, 32)   0           reshape
_3[0][0]
________________________________________________________________________
__________________________
flatten_13 (Flatten)            (None, 6272)         0           max_poo
ling2d_3[0][0]
________________________________________________________________________
__________________________
dense_16 (Dense)                (None, 512)          3211776     flatten
_13[0][0]
________________________________________________________________________
__________________________
dense_17 (Dense)                (None, 10)           5130        dense_1
6[0][0]
========================================================================
==========================
Total params: 3,218,026
Trainable params: 3,218,026
Non-trainable params: 0
________________________________________________________________________
__________________________
Train on 10240 samples, validate on 2560 samples
Epoch 1/80
10240/10240 [==============================] - 63s 6ms/step - loss: 1.33
79 - acc: 0.3723 - val_loss: 1.2564 - val_acc: 0.4250
Epoch 2/80
10240/10240 [==============================] - 61s 6ms/step - loss: 1.21
93 - acc: 0.4494 - val_loss: 1.2324 - val_acc: 0.4207
Epoch 3/80
10240/10240 [==============================] - 61s 6ms/step - loss: 1.18
53 - acc: 0.4743 - val_loss: 1.1982 - val_acc: 0.4680
```

```
Epoch 4/80
10240/10240 [==============================] - 61s 6ms/step - loss: 1.16
05 - acc: 0.4908 - val_loss: 1.1821 - val_acc: 0.4727
Epoch 5/80
10240/10240 [==============================] - 61s 6ms/step - loss: 1.13
63 - acc: 0.5068 - val_loss: 1.1649 - val_acc: 0.4832
Epoch 6/80
10240/10240 [==============================] - 61s 6ms/step - loss: 1.11
97 - acc: 0.5166 - val_loss: 1.2203 - val_acc: 0.4516
Epoch 7/80
10240/10240 [==============================] - 61s 6ms/step - loss: 1.10
11 - acc: 0.5237 - val_loss: 1.2069 - val_acc: 0.4734
Epoch 8/80
10240/10240 [==============================] - 61s 6ms/step - loss: 1.07
74 - acc: 0.5385 - val_loss: 1.1475 - val_acc: 0.4934
Epoch 9/80
10240/10240 [==============================] - 61s 6ms/step - loss: 1.05
42 - acc: 0.5419 - val_loss: 1.1572 - val_acc: 0.4883
Epoch 10/80
10240/10240 [==============================] - 61s 6ms/step - loss: 1.02
77 - acc: 0.5640 - val_loss: 1.1376 - val_acc: 0.5020
Epoch 11/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.99
59 - acc: 0.5797 - val_loss: 1.1461 - val_acc: 0.5062
Epoch 12/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.97
07 - acc: 0.5914 - val_loss: 1.1634 - val_acc: 0.4938
Epoch 13/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.94
20 - acc: 0.6081 - val_loss: 1.1302 - val_acc: 0.5094
Epoch 14/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.90
86 - acc: 0.6191 - val_loss: 1.1663 - val_acc: 0.5109
Epoch 15/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.87
81 - acc: 0.6426 - val_loss: 1.1650 - val_acc: 0.5129
Epoch 16/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.84
44 - acc: 0.6562 - val_loss: 1.1968 - val_acc: 0.5098
Epoch 17/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.80
50 - acc: 0.6697 - val_loss: 1.2036 - val_acc: 0.5090s: 0.8061 -
Epoch 18/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.77
48 - acc: 0.6937 - val_loss: 1.2115 - val_acc: 0.5098
Epoch 19/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.72
86 - acc: 0.7125 - val_loss: 1.2511 - val_acc: 0.50271
Epoch 20/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.69
28 - acc: 0.7253 - val_loss: 1.2751 - val_acc: 0.5195
Epoch 21/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.65
04 - acc: 0.7538 - val_loss: 1.2873 - val_acc: 0.5184
Epoch 22/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.59
94 - acc: 0.7745 - val_loss: 1.3813 - val_acc: 0.5137
Epoch 23/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.55
59 - acc: 0.7935 - val_loss: 1.4076 - val_acc: 0.5199
Epoch 24/80
```

```
10240/10240 [==============================] - 61s 6ms/step - loss: 0.51
30 - acc: 0.8149 - val_loss: 1.4890 - val_acc: 0.5199
Epoch 25/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.47
36 - acc: 0.8296 - val_loss: 1.5443 - val_acc: 0.5188
Epoch 26/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.44
99 - acc: 0.8400 - val_loss: 1.5596 - val_acc: 0.5105
Epoch 27/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.38
73 - acc: 0.8675 - val_loss: 1.7113 - val_acc: 0.5219
Epoch 28/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.35
40 - acc: 0.8803 - val_loss: 1.8195 - val_acc: 0.5074
Epoch 29/80
10240/10240 [==============================] - 62s 6ms/step - loss: 0.31
88 - acc: 0.8959 - val_loss: 1.8452 - val_acc: 0.5230
Epoch 30/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.28
58 - acc: 0.9074 - val_loss: 1.9602 - val_acc: 0.5164
Epoch 31/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.24
75 - acc: 0.9212 - val_loss: 2.0505 - val_acc: 0.5098: 0.2434  - ETA: 1s
- loss: 0.2456 - a
Epoch 32/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.24
08 - acc: 0.9265 - val_loss: 2.1508 - val_acc: 0.5258
Epoch 33/80
10240/10240 [==============================] - 62s 6ms/step - loss: 0.20
14 - acc: 0.9413 - val_loss: 2.2546 - val_acc: 0.5137
Epoch 34/80
10240/10240 [==============================] - 62s 6ms/step - loss: 0.18
91 - acc: 0.9441 - val_loss: 2.2878 - val_acc: 0.5211
Epoch 35/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.17
23 - acc: 0.9507 - val_loss: 2.4490 - val_acc: 0.5281
Epoch 36/80
10240/10240 [==============================] - 62s 6ms/step - loss: 0.14
87 - acc: 0.9605 - val_loss: 2.5448 - val_acc: 0.5215
Epoch 37/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.15
07 - acc: 0.9595 - val_loss: 2.5540 - val_acc: 0.5285
Epoch 38/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.13
31 - acc: 0.9669 - val_loss: 2.6885 - val_acc: 0.5238
Epoch 39/80
10240/10240 [==============================] - 59s 6ms/step - loss: 0.12
19 - acc: 0.9698 - val_loss: 2.7687 - val_acc: 0.5277
Epoch 40/80
10240/10240 [==============================] - 59s 6ms/step - loss: 0.12
64 - acc: 0.9691 - val_loss: 2.8236 - val_acc: 0.5176
Epoch 41/80
10240/10240 [==============================] - 59s 6ms/step - loss: 0.12
02 - acc: 0.9685 - val_loss: 2.8247 - val_acc: 0.5230
Epoch 42/80
10240/10240 [==============================] - 60s 6ms/step - loss: 0.12
18 - acc: 0.9690 - val_loss: 2.8291 - val_acc: 0.5195
Epoch 43/80
10240/10240 [==============================] - 59s 6ms/step - loss: 0.11
46 - acc: 0.9718 - val_loss: 3.0301 - val_acc: 0.5188
Epoch 44/80
```

```
10240/10240 [==============================] - 59s 6ms/step - loss: 0.08
52 - acc: 0.9832 - val_loss: 3.0354 - val_acc: 0.5180
Epoch 45/80
10240/10240 [==============================] - 59s 6ms/step - loss: 0.09
54 - acc: 0.9804 - val_loss: 3.0900 - val_acc: 0.5258
Epoch 46/80
10240/10240 [==============================] - 59s 6ms/step - loss: 0.12
56 - acc: 0.9654 - val_loss: 2.9120 - val_acc: 0.5246
Epoch 47/80
10240/10240 [==============================] - 59s 6ms/step - loss: 0.09
58 - acc: 0.9781 - val_loss: 3.1255 - val_acc: 0.5207
Epoch 48/80
10240/10240 [==============================] - 59s 6ms/step - loss: 0.06
86 - acc: 0.9886 - val_loss: 3.1843 - val_acc: 0.5219
Epoch 49/80
10240/10240 [==============================] - 59s 6ms/step - loss: 0.09
92 - acc: 0.9778 - val_loss: 3.1549 - val_acc: 0.5223
Epoch 50/80
10240/10240 [==============================] - 59s 6ms/step - loss: 0.07
52 - acc: 0.9857 - val_loss: 3.2917 - val_acc: 0.5191
Epoch 51/80
10240/10240 [==============================] - 59s 6ms/step - loss: 0.09
52 - acc: 0.9768 - val_loss: 3.3177 - val_acc: 0.5031
Epoch 52/80
10240/10240 [==============================] - 59s 6ms/step - loss: 0.13
64 - acc: 0.9615 - val_loss: 3.1806 - val_acc: 0.5152
Epoch 53/80
10240/10240 [==============================] - 59s 6ms/step - loss: 0.08
20 - acc: 0.9827 - val_loss: 3.2101 - val_acc: 0.5273
Epoch 54/80
10240/10240 [==============================] - 60s 6ms/step - loss: 0.06
48 - acc: 0.9885 - val_loss: 3.1744 - val_acc: 0.5238
Epoch 55/80
10240/10240 [==============================] - 60s 6ms/step - loss: 0.06
33 - acc: 0.9884 - val_loss: 3.3135 - val_acc: 0.5227
Epoch 56/80
10240/10240 [==============================] - 64s 6ms/step - loss: 0.08
73 - acc: 0.9791 - val_loss: 3.2164 - val_acc: 0.5266
Epoch 57/80
10240/10240 [==============================] - 62s 6ms/step - loss: 0.06
90 - acc: 0.9869 - val_loss: 3.3388 - val_acc: 0.5152
Epoch 58/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.07
23 - acc: 0.9857 - val_loss: 3.2813 - val_acc: 0.5293
Epoch 59/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.06
21 - acc: 0.9889 - val_loss: 3.3823 - val_acc: 0.5227
Epoch 60/80
10240/10240 [==============================] - 62s 6ms/step - loss: 0.08
02 - acc: 0.9825 - val_loss: 3.3445 - val_acc: 0.5082
Epoch 61/80
10240/10240 [==============================] - 67s 7ms/step - loss: 0.09
89 - acc: 0.9749 - val_loss: 3.3139 - val_acc: 0.5305
Epoch 62/80
10240/10240 [==============================] - 62s 6ms/step - loss: 0.04
61 - acc: 0.9945 - val_loss: 3.4244 - val_acc: 0.5270
Epoch 63/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.07
07 - acc: 0.9850 - val_loss: 3.4401 - val_acc: 0.5121
Epoch 64/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.06
```

```
01 - acc: 0.9897 - val_loss: 3.3461 - val_acc: 0.5262
Epoch 65/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.06
44 - acc: 0.9859 - val_loss: 3.3416 - val_acc: 0.5250
Epoch 66/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.08
51 - acc: 0.9817 - val_loss: 3.3186 - val_acc: 0.5273
Epoch 67/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.04
19 - acc: 0.9954 - val_loss: 3.4118 - val_acc: 0.5293
Epoch 68/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.04
61 - acc: 0.9937 - val_loss: 3.4408 - val_acc: 0.5336
Epoch 69/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.11
04 - acc: 0.9710 - val_loss: 3.5225 - val_acc: 0.5246
Epoch 70/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.07
28 - acc: 0.9836 - val_loss: 3.3697 - val_acc: 0.5289
Epoch 71/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.04
04 - acc: 0.9947 - val_loss: 3.4486 - val_acc: 0.5309
Epoch 72/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.03
60 - acc: 0.9964 - val_loss: 3.4153 - val_acc: 0.5383
Epoch 73/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.04
33 - acc: 0.9941 - val_loss: 3.4759 - val_acc: 0.5289
Epoch 74/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.05
12 - acc: 0.9903 - val_loss: 3.5384 - val_acc: 0.5273
Epoch 75/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.12
46 - acc: 0.9643 - val_loss: 3.5233 - val_acc: 0.5105
Epoch 76/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.06
21 - acc: 0.9872 - val_loss: 3.3795 - val_acc: 0.5227
Epoch 77/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.02
95 - acc: 0.9976 - val_loss: 3.4397 - val_acc: 0.5340
Epoch 78/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.03
38 - acc: 0.9968 - val_loss: 3.4095 - val_acc: 0.5340
Epoch 79/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.04
49 - acc: 0.9925 - val_loss: 3.5892 - val_acc: 0.5230
Epoch 80/80
10240/10240 [==============================] - 61s 6ms/step - loss: 0.11
55 - acc: 0.9688 - val_loss: 3.3730 - val_acc: 0.5219
Evaluating model.
2560/2560 [==============================] - 3s 1ms/step
loss:3.373025028407574
acc: 0.521875
```

Training the data with fully connected GCN

In [58]:

```
A0 = sp.csr_matrix(A.shape, dtype=np.float32)
print(A0.shape, A0.nnz)
model_no_graph = graph_convolution_one_layer_model(A0)
model_no_graph.summary()
model_no_graph.fit(X_train,
                    y_train,
                    batch_size=user_model_batch,
                    validation_data=validation_data,
                    epochs=epochs)
print('Evaluating model.')
eval_results = model_no_graph.evaluate(X_test,
                                       y_test,
                                       batch_size=user_model_batch)
print('loss: {}\n'
      'acc: {}'.format(*eval_results))

test_scores.append({
    'model': 'GCN graph',
    'accuracy': eval_results[1]
})


def fc_model(N=28 * 28, F=1,
             n_out=10,
             l2_reg=user_reguralization_rate,
             learning_rate=user_model_learning_rate):
    '''-connected model classification.
    '''
    X_in = Input(shape=(N, F))

    fc = Dense(10, activation='relu',
               kernel_regularizer=l2(l2_reg),
               use_bias=True)(Flatten()(X_in))

    output = Dense(n_out, activation='softmax')(fc)

    # Build model
    model = Model(inputs=X_in, outputs=output)
    model.compile(optimizer='adam', loss='sparse_categorical_crossentropy', metrics=['a
ccuracy'])

    return model

model_fc = fc_model()
model_fc.summary()
model_fc.fit(X_train,
                    y_train,
                    batch_size=user_model_batch,
                    validation_data=validation_data,
                    epochs=epochs)
```

```
(784, 784) 0
Model: "model_14"
__________________________________________________________________________
________________________
Layer (type)                    Output Shape         Param #     Connected
to
==========================================================================
========================
input_26 (InputLayer)           (None, 784, 1)       0
__________________________________________________________________________
________________________
input_27 (InputLayer)           (784, 784)           0
__________________________________________________________________________
________________________
graph_conv_16 (GraphConv)       (None, 784, 10)      20          input_26
[0][0]
                                                                 input_27
[0][0]
__________________________________________________________________________
________________________
flatten_14 (Flatten)            (None, 7840)         0           graph_con
v_16[0][0]
__________________________________________________________________________
________________________
dense_18 (Dense)                (None, 10)           78410       flatten_1
4[0][0]
==========================================================================
========================
Total params: 78,430
Trainable params: 78,430
Non-trainable params: 0
__________________________________________________________________________
________________________
Train on 10240 samples, validate on 2560 samples
Epoch 1/80
10240/10240 [==============================] - 6s 554us/step - loss: 1.338
3 - acc: 0.3685 - val_loss: 1.2614 - val_acc: 0.4352
Epoch 2/80
10240/10240 [==============================] - 5s 458us/step - loss: 1.234
9 - acc: 0.4484 - val_loss: 1.2253 - val_acc: 0.4566
Epoch 3/80
10240/10240 [==============================] - 4s 421us/step - loss: 1.201
3 - acc: 0.4686 - val_loss: 1.2047 - val_acc: 0.4574
Epoch 4/80
10240/10240 [==============================] - 4s 429us/step - loss: 1.193
6 - acc: 0.4726 - val_loss: 1.2232 - val_acc: 0.4625
Epoch 5/80
10240/10240 [==============================] - 4s 427us/step - loss: 1.178
2 - acc: 0.4787 - val_loss: 1.2308 - val_acc: 0.4590
Epoch 6/80
10240/10240 [==============================] - 4s 391us/step - loss: 1.172
7 - acc: 0.4896 - val_loss: 1.1976 - val_acc: 0.4633
Epoch 7/80
10240/10240 [==============================] - 4s 389us/step - loss: 1.157
8 - acc: 0.4924 - val_loss: 1.1816 - val_acc: 0.4719
Epoch 8/80
10240/10240 [==============================] - 4s 389us/step - loss: 1.155
9 - acc: 0.4984 - val_loss: 1.1880 - val_acc: 0.4734
Epoch 9/80
10240/10240 [==============================] - 4s 413us/step - loss: 1.146
3 - acc: 0.5019 - val_loss: 1.1909 - val_acc: 0.4758
```

```
Epoch 10/80
10240/10240 [==============================] - 4s 389us/step - loss: 1.139
6 - acc: 0.5070 - val_loss: 1.1935 - val_acc: 0.4750
Epoch 11/80
10240/10240 [==============================] - 4s 391us/step - loss: 1.135
7 - acc: 0.5054 - val_loss: 1.1990 - val_acc: 0.4777
Epoch 12/80
10240/10240 [==============================] - 4s 391us/step - loss: 1.126
9 - acc: 0.5134 - val_loss: 1.2451 - val_acc: 0.4574
Epoch 13/80
10240/10240 [==============================] - 4s 433us/step - loss: 1.139
8 - acc: 0.5088 - val_loss: 1.2044 - val_acc: 0.4699
Epoch 14/80
10240/10240 [==============================] - 5s 446us/step - loss: 1.125
0 - acc: 0.5120 - val_loss: 1.1957 - val_acc: 0.4645
Epoch 15/80
10240/10240 [==============================] - 4s 391us/step - loss: 1.109
0 - acc: 0.5259 - val_loss: 1.1920 - val_acc: 0.4691
Epoch 16/80
10240/10240 [==============================] - 4s 394us/step - loss: 1.113
7 - acc: 0.5175 - val_loss: 1.1798 - val_acc: 0.4848
Epoch 17/80
10240/10240 [==============================] - 4s 416us/step - loss: 1.104
1 - acc: 0.5289 - val_loss: 1.1990 - val_acc: 0.4691
Epoch 18/80
10240/10240 [==============================] - 4s 394us/step - loss: 1.102
2 - acc: 0.5239 - val_loss: 1.1936 - val_acc: 0.4797
Epoch 19/80
10240/10240 [==============================] - 4s 394us/step - loss: 1.099
0 - acc: 0.5290 - val_loss: 1.1892 - val_acc: 0.4742
Epoch 20/80
10240/10240 [==============================] - 4s 392us/step - loss: 1.098
6 - acc: 0.5305 - val_loss: 1.2019 - val_acc: 0.4699
Epoch 21/80
10240/10240 [==============================] - 4s 420us/step - loss: 1.089
7 - acc: 0.5319 - val_loss: 1.1842 - val_acc: 0.4809
Epoch 22/80
10240/10240 [==============================] - 4s 394us/step - loss: 1.095
5 - acc: 0.5343 - val_loss: 1.2270 - val_acc: 0.4578
Epoch 23/80
10240/10240 [==============================] - 4s 393us/step - loss: 1.081
2 - acc: 0.5394 - val_loss: 1.2369 - val_acc: 0.4711
Epoch 24/80
10240/10240 [==============================] - 4s 396us/step - loss: 1.082
5 - acc: 0.5386 - val_loss: 1.1792 - val_acc: 0.4719
Epoch 25/80
10240/10240 [==============================] - 4s 417us/step - loss: 1.079
0 - acc: 0.5396 - val_loss: 1.2101 - val_acc: 0.4629
Epoch 26/80
10240/10240 [==============================] - 4s 395us/step - loss: 1.076
1 - acc: 0.5427 - val_loss: 1.1897 - val_acc: 0.4855
Epoch 27/80
10240/10240 [==============================] - 4s 392us/step - loss: 1.070
0 - acc: 0.5450 - val_loss: 1.1931 - val_acc: 0.4781
Epoch 28/80
10240/10240 [==============================] - 4s 394us/step - loss: 1.071
5 - acc: 0.5475 - val_loss: 1.1961 - val_acc: 0.4703
Epoch 29/80
10240/10240 [==============================] - 4s 417us/step - loss: 1.059
8 - acc: 0.5500 - val_loss: 1.1983 - val_acc: 0.4684
Epoch 30/80
```

```
10240/10240 [==============================] - 4s 394us/step - loss: 1.060
5 - acc: 0.5455 - val_loss: 1.1859 - val_acc: 0.4734
Epoch 31/80
10240/10240 [==============================] - 4s 394us/step - loss: 1.058
8 - acc: 0.5523 - val_loss: 1.2992 - val_acc: 0.4539
Epoch 32/80
10240/10240 [==============================] - 4s 395us/step - loss: 1.059
1 - acc: 0.5538 - val_loss: 1.1762 - val_acc: 0.4844
Epoch 33/80
10240/10240 [==============================] - 4s 434us/step - loss: 1.055
5 - acc: 0.5563 - val_loss: 1.1868 - val_acc: 0.4805
Epoch 34/80
10240/10240 [==============================] - 4s 430us/step - loss: 1.053
4 - acc: 0.5536 - val_loss: 1.2018 - val_acc: 0.4770
Epoch 35/80
10240/10240 [==============================] - 4s 396us/step - loss: 1.047
2 - acc: 0.5548 - val_loss: 1.2061 - val_acc: 0.4727
Epoch 36/80
10240/10240 [==============================] - 4s 416us/step - loss: 1.042
2 - acc: 0.5640 - val_loss: 1.2140 - val_acc: 0.4727
Epoch 37/80
10240/10240 [==============================] - 4s 399us/step - loss: 1.042
8 - acc: 0.5604 - val_loss: 1.1940 - val_acc: 0.4801
Epoch 38/80
10240/10240 [==============================] - 4s 394us/step - loss: 1.033
8 - acc: 0.5646 - val_loss: 1.2052 - val_acc: 0.4824
Epoch 39/80
10240/10240 [==============================] - 4s 395us/step - loss: 1.030
7 - acc: 0.5652 - val_loss: 1.1945 - val_acc: 0.4781
Epoch 40/80
10240/10240 [==============================] - 4s 418us/step - loss: 1.030
4 - acc: 0.5681 - val_loss: 1.2073 - val_acc: 0.4785
Epoch 41/80
10240/10240 [==============================] - 4s 397us/step - loss: 1.033
8 - acc: 0.5666 - val_loss: 1.2028 - val_acc: 0.4742
Epoch 42/80
10240/10240 [==============================] - 4s 409us/step - loss: 1.028
3 - acc: 0.5696 - val_loss: 1.2004 - val_acc: 0.4785
Epoch 43/80
10240/10240 [==============================] - 4s 386us/step - loss: 1.026
4 - acc: 0.5707 - val_loss: 1.2327 - val_acc: 0.4699
Epoch 44/80
10240/10240 [==============================] - 4s 410us/step - loss: 1.029
6 - acc: 0.5660 - val_loss: 1.2598 - val_acc: 0.4582
Epoch 45/80
10240/10240 [==============================] - 4s 387us/step - loss: 1.026
4 - acc: 0.5727 - val_loss: 1.2061 - val_acc: 0.4715
Epoch 46/80
10240/10240 [==============================] - 4s 387us/step - loss: 1.012
0 - acc: 0.5771 - val_loss: 1.1972 - val_acc: 0.4801
Epoch 47/80
10240/10240 [==============================] - 4s 386us/step - loss: 1.015
7 - acc: 0.5755 - val_loss: 1.2462 - val_acc: 0.4754
Epoch 48/80
10240/10240 [==============================] - 4s 405us/step - loss: 1.019
7 - acc: 0.5739 - val_loss: 1.2126 - val_acc: 0.4750
Epoch 49/80
10240/10240 [==============================] - 4s 384us/step - loss: 1.016
7 - acc: 0.5756 - val_loss: 1.2036 - val_acc: 0.4852
Epoch 50/80
10240/10240 [==============================] - 4s 384us/step - loss: 1.011
```

```
8 - acc: 0.5784 - val_loss: 1.2660 - val_acc: 0.4621
Epoch 51/80
10240/10240 [==============================] - 4s 384us/step - loss: 1.005
9 - acc: 0.5836 - val_loss: 1.2342 - val_acc: 0.4770
Epoch 52/80
10240/10240 [==============================] - 4s 407us/step - loss: 0.997
8 - acc: 0.5875 - val_loss: 1.1995 - val_acc: 0.4789
Epoch 53/80
10240/10240 [==============================] - 4s 386us/step - loss: 1.004
4 - acc: 0.5803 - val_loss: 1.2469 - val_acc: 0.4668
Epoch 54/80
10240/10240 [==============================] - 4s 386us/step - loss: 0.999
9 - acc: 0.5876 - val_loss: 1.1998 - val_acc: 0.4773
Epoch 55/80
10240/10240 [==============================] - 4s 384us/step - loss: 1.001
6 - acc: 0.5852 - val_loss: 1.2293 - val_acc: 0.4797
Epoch 56/80
10240/10240 [==============================] - 4s 407us/step - loss: 0.993
6 - acc: 0.5867 - val_loss: 1.2548 - val_acc: 0.4680
Epoch 57/80
10240/10240 [==============================] - 4s 384us/step - loss: 0.992
5 - acc: 0.5918 - val_loss: 1.2144 - val_acc: 0.4824
Epoch 58/80
10240/10240 [==============================] - 4s 382us/step - loss: 0.993
1 - acc: 0.5940 - val_loss: 1.2169 - val_acc: 0.4863
Epoch 59/80
10240/10240 [==============================] - 4s 383us/step - loss: 0.995
9 - acc: 0.5876 - val_loss: 1.2958 - val_acc: 0.4637
Epoch 60/80
10240/10240 [==============================] - 4s 406us/step - loss: 0.989
8 - acc: 0.5901 - val_loss: 1.3097 - val_acc: 0.4484
Epoch 61/80
10240/10240 [==============================] - 4s 384us/step - loss: 0.982
0 - acc: 0.5932 - val_loss: 1.2245 - val_acc: 0.4746
Epoch 62/80
10240/10240 [==============================] - 4s 384us/step - loss: 0.981
2 - acc: 0.5947 - val_loss: 1.2262 - val_acc: 0.4789
Epoch 63/80
10240/10240 [==============================] - 4s 384us/step - loss: 0.979
8 - acc: 0.5900 - val_loss: 1.2410 - val_acc: 0.4805
Epoch 64/80
10240/10240 [==============================] - 4s 408us/step - loss: 0.982
8 - acc: 0.5940 - val_loss: 1.2333 - val_acc: 0.4754
Epoch 65/80
10240/10240 [==============================] - 4s 384us/step - loss: 0.974
3 - acc: 0.5969 - val_loss: 1.2525 - val_acc: 0.4699
Epoch 66/80
10240/10240 [==============================] - 4s 385us/step - loss: 0.975
1 - acc: 0.5964 - val_loss: 1.2170 - val_acc: 0.4754
Epoch 67/80
10240/10240 [==============================] - 4s 384us/step - loss: 0.967
3 - acc: 0.6049 - val_loss: 1.2782 - val_acc: 0.4703
Epoch 68/80
10240/10240 [==============================] - 4s 408us/step - loss: 0.977
3 - acc: 0.5974 - val_loss: 1.2615 - val_acc: 0.4730
Epoch 69/80
10240/10240 [==============================] - 4s 385us/step - loss: 0.975
3 - acc: 0.5968 - val_loss: 1.2473 - val_acc: 0.4668
Epoch 70/80
10240/10240 [==============================] - 4s 383us/step - loss: 0.964
6 - acc: 0.6037 - val_loss: 1.2613 - val_acc: 0.4645
```

```
Epoch 71/80
10240/10240 [==============================] - 4s 385us/step - loss: 0.967
6 - acc: 0.6054 - val_loss: 1.2382 - val_acc: 0.4719
Epoch 72/80
10240/10240 [==============================] - 4s 425us/step - loss: 0.960
2 - acc: 0.6063 - val_loss: 1.2794 - val_acc: 0.4695
Epoch 73/80
10240/10240 [==============================] - 4s 386us/step - loss: 0.975
8 - acc: 0.6004 - val_loss: 1.2753 - val_acc: 0.4582
Epoch 74/80
10240/10240 [==============================] - 4s 386us/step - loss: 0.962
2 - acc: 0.6022 - val_loss: 1.2677 - val_acc: 0.4750
Epoch 75/80
10240/10240 [==============================] - 4s 384us/step - loss: 0.970
4 - acc: 0.6033 - val_loss: 1.2389 - val_acc: 0.4867
Epoch 76/80
10240/10240 [==============================] - 4s 408us/step - loss: 0.952
7 - acc: 0.6093 - val_loss: 1.2898 - val_acc: 0.4617
Epoch 77/80
10240/10240 [==============================] - 4s 386us/step - loss: 0.960
9 - acc: 0.6020 - val_loss: 1.2408 - val_acc: 0.4789
Epoch 78/80
10240/10240 [==============================] - 4s 385us/step - loss: 0.958
0 - acc: 0.6082 - val_loss: 1.2838 - val_acc: 0.4711
Epoch 79/80
10240/10240 [==============================] - 4s 386us/step - loss: 0.954
7 - acc: 0.6085 - val_loss: 1.2603 - val_acc: 0.4723
Epoch 80/80
10240/10240 [==============================] - 4s 406us/step - loss: 0.961
4 - acc: 0.6116 - val_loss: 1.2470 - val_acc: 0.4738
Evaluating model.
2560/2560 [==============================] - 0s 160us/step
loss: 1.2469926431775094
acc: 0.473828125
Model: "model_15"
_________________________________________________________________
Layer (type)                 Output Shape              Param #   
=================================================================
input_28 (InputLayer)        (None, 784, 1)            0         
_________________________________________________________________
flatten_15 (Flatten)         (None, 784)               0         
_________________________________________________________________
dense_19 (Dense)             (None, 10)                7850      
_________________________________________________________________
dense_20 (Dense)             (None, 10)                110       
=================================================================
Total params: 7,960
Trainable params: 7,960
Non-trainable params: 0
_________________________________________________________________
Train on 10240 samples, validate on 2560 samples
Epoch 1/80
10240/10240 [==============================] - 2s 183us/step - loss: 1.488
7 - acc: 0.3212 - val_loss: 1.3156 - val_acc: 0.3719
Epoch 2/80
10240/10240 [==============================] - 1s 69us/step - loss: 1.2948
- acc: 0.3964 - val_loss: 1.2885 - val_acc: 0.3984
Epoch 3/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.2626
- acc: 0.4240 - val_loss: 1.2609 - val_acc: 0.4258
Epoch 4/80
```

```
10240/10240 [==============================] - 1s 69us/step - loss: 1.2387
- acc: 0.4374 - val_loss: 1.2441 - val_acc: 0.4297
Epoch 5/80
10240/10240 [==============================] - 1s 69us/step - loss: 1.2320
- acc: 0.4439 - val_loss: 1.2396 - val_acc: 0.4465
Epoch 6/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.2186
- acc: 0.4574 - val_loss: 1.2560 - val_acc: 0.4230
Epoch 7/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.2026
- acc: 0.4728 - val_loss: 1.2511 - val_acc: 0.4547
Epoch 8/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.2031
- acc: 0.4677 - val_loss: 1.2251 - val_acc: 0.4453
Epoch 9/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.1964
- acc: 0.4747 - val_loss: 1.2274 - val_acc: 0.4535
Epoch 10/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1953
- acc: 0.4770 - val_loss: 1.2208 - val_acc: 0.4578
Epoch 11/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1882
- acc: 0.4844 - val_loss: 1.2261 - val_acc: 0.4582
Epoch 12/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.1810
- acc: 0.4812 - val_loss: 1.2051 - val_acc: 0.4629
Epoch 13/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.1767
- acc: 0.4894 - val_loss: 1.2438 - val_acc: 0.4578s - loss: 1.1771 - acc:
0.48
Epoch 14/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.1792
- acc: 0.4881 - val_loss: 1.2179 - val_acc: 0.4570
Epoch 15/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.1705
- acc: 0.4932 - val_loss: 1.2096 - val_acc: 0.4684
Epoch 16/80
10240/10240 [==============================] - 1s 69us/step - loss: 1.1736
- acc: 0.4908 - val_loss: 1.2500 - val_acc: 0.4453
Epoch 17/80
10240/10240 [==============================] - 1s 69us/step - loss: 1.1650
- acc: 0.4965 - val_loss: 1.2190 - val_acc: 0.4535
Epoch 18/80
10240/10240 [==============================] - 1s 92us/step - loss: 1.1638
- acc: 0.5017 - val_loss: 1.2285 - val_acc: 0.4539
Epoch 19/80
10240/10240 [==============================] - 1s 79us/step - loss: 1.1622
- acc: 0.4961 - val_loss: 1.2014 - val_acc: 0.4723
Epoch 20/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.1600
- acc: 0.4971 - val_loss: 1.2254 - val_acc: 0.4539
Epoch 21/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1593
- acc: 0.4962 - val_loss: 1.2010 - val_acc: 0.4719
Epoch 22/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.1575
- acc: 0.5002 - val_loss: 1.2223 - val_acc: 0.4527
Epoch 23/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.1581
- acc: 0.5009 - val_loss: 1.2046 - val_acc: 0.4594
Epoch 24/80
```

```
10240/10240 [==============================] - 1s 69us/step - loss: 1.1546
- acc: 0.4998 - val_loss: 1.2045 - val_acc: 0.4758
Epoch 25/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.1495
- acc: 0.5044 - val_loss: 1.2177 - val_acc: 0.4688
Epoch 26/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1479
- acc: 0.5091 - val_loss: 1.2108 - val_acc: 0.4605
Epoch 27/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1496
- acc: 0.5001 - val_loss: 1.2056 - val_acc: 0.4734
Epoch 28/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1475
- acc: 0.5088 - val_loss: 1.2025 - val_acc: 0.4695
Epoch 29/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1488
- acc: 0.5104 - val_loss: 1.2344 - val_acc: 0.4586 loss: 1.1477 - acc: 0.5
1
Epoch 30/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1460
- acc: 0.5111 - val_loss: 1.1968 - val_acc: 0.4793
Epoch 31/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.1436
- acc: 0.5088 - val_loss: 1.2130 - val_acc: 0.4645
Epoch 32/80
10240/10240 [==============================] - 1s 69us/step - loss: 1.1444
- acc: 0.5116 - val_loss: 1.2090 - val_acc: 0.4691
Epoch 33/80
10240/10240 [==============================] - 1s 69us/step - loss: 1.1442
- acc: 0.5107 - val_loss: 1.2070 - val_acc: 0.4785
Epoch 34/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.1383
- acc: 0.5144 - val_loss: 1.2051 - val_acc: 0.4781
Epoch 35/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.1395
- acc: 0.5177 - val_loss: 1.2017 - val_acc: 0.4773
Epoch 36/80
10240/10240 [==============================] - 1s 65us/step - loss: 1.1383
- acc: 0.5133 - val_loss: 1.2087 - val_acc: 0.4652
Epoch 37/80
10240/10240 [==============================] - 1s 65us/step - loss: 1.1422
- acc: 0.5088 - val_loss: 1.2535 - val_acc: 0.4488
Epoch 38/80
10240/10240 [==============================] - 1s 69us/step - loss: 1.1411
- acc: 0.5101 - val_loss: 1.2074 - val_acc: 0.4645
Epoch 39/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.1437
- acc: 0.5097 - val_loss: 1.2098 - val_acc: 0.4676
Epoch 40/80
10240/10240 [==============================] - 1s 81us/step - loss: 1.1339
- acc: 0.5154 - val_loss: 1.2010 - val_acc: 0.4656
Epoch 41/80
10240/10240 [==============================] - 1s 89us/step - loss: 1.1359
- acc: 0.5159 - val_loss: 1.2068 - val_acc: 0.4699
Epoch 42/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1384
- acc: 0.5153 - val_loss: 1.1972 - val_acc: 0.4762
Epoch 43/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1325
- acc: 0.5124 - val_loss: 1.2015 - val_acc: 0.4773
Epoch 44/80
```

```
10240/10240 [==============================] - 1s 67us/step - loss: 1.1301
- acc: 0.5163 - val_loss: 1.2066 - val_acc: 0.4781
Epoch 45/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1334
- acc: 0.5141 - val_loss: 1.1924 - val_acc: 0.4859
Epoch 46/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.1381
- acc: 0.5194 - val_loss: 1.2077 - val_acc: 0.4664
Epoch 47/80
10240/10240 [==============================] - 1s 69us/step - loss: 1.1288
- acc: 0.5210 - val_loss: 1.2529 - val_acc: 0.4637
Epoch 48/80
10240/10240 [==============================] - 1s 69us/step - loss: 1.1354
- acc: 0.5144 - val_loss: 1.1998 - val_acc: 0.4871
Epoch 49/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.1334
- acc: 0.5208 - val_loss: 1.2198 - val_acc: 0.4578
Epoch 50/80
10240/10240 [==============================] - 1s 69us/step - loss: 1.1262
- acc: 0.5224 - val_loss: 1.2198 - val_acc: 0.4680 - loss: 1.1257 - acc:
0.522
Epoch 51/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1309
- acc: 0.5228 - val_loss: 1.2114 - val_acc: 0.4820
Epoch 52/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1294
- acc: 0.5200 - val_loss: 1.2065 - val_acc: 0.4840
Epoch 53/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1268
- acc: 0.5178 - val_loss: 1.2108 - val_acc: 0.4832s - loss: 1.1259 - acc:
0.517
Epoch 54/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1274
- acc: 0.5204 - val_loss: 1.2101 - val_acc: 0.4527
Epoch 55/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.1274
- acc: 0.5170 - val_loss: 1.1972 - val_acc: 0.4742
Epoch 56/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.1285
- acc: 0.5231 - val_loss: 1.2863 - val_acc: 0.4324 0s - loss: 1.1202 - ac
Epoch 57/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.1236
- acc: 0.5221 - val_loss: 1.2086 - val_acc: 0.4598
Epoch 58/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1231
- acc: 0.5224 - val_loss: 1.2048 - val_acc: 0.4543
Epoch 59/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1233
- acc: 0.5236 - val_loss: 1.2514 - val_acc: 0.4418
Epoch 60/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1170
- acc: 0.5263 - val_loss: 1.2498 - val_acc: 0.4445
Epoch 61/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.1177
- acc: 0.5308 - val_loss: 1.2121 - val_acc: 0.4648
Epoch 62/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.1131
- acc: 0.5259 - val_loss: 1.2137 - val_acc: 0.4676
Epoch 63/80
10240/10240 [==============================] - 1s 94us/step - loss: 1.1157
- acc: 0.5276 - val_loss: 1.1929 - val_acc: 0.4754
```

```
Epoch 64/80
10240/10240 [==============================] - 1s 77us/step - loss: 1.1114
- acc: 0.5312 - val_loss: 1.2039 - val_acc: 0.4820
Epoch 65/80
10240/10240 [==============================] - 1s 69us/step - loss: 1.1082
- acc: 0.5274 - val_loss: 1.2155 - val_acc: 0.4605
Epoch 66/80
10240/10240 [==============================] - 1s 69us/step - loss: 1.1024
- acc: 0.5321 - val_loss: 1.1948 - val_acc: 0.4871
Epoch 67/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.1077
- acc: 0.5346 - val_loss: 1.2184 - val_acc: 0.4770
Epoch 68/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.1148
- acc: 0.5296 - val_loss: 1.2049 - val_acc: 0.4840
Epoch 69/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.1060
- acc: 0.5304 - val_loss: 1.1900 - val_acc: 0.4738
Epoch 70/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.1100
- acc: 0.5214 - val_loss: 1.1885 - val_acc: 0.4770
Epoch 71/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.1073
- acc: 0.5282 - val_loss: 1.1955 - val_acc: 0.4707s - loss: 1.1041 - acc:
0.5
Epoch 72/80
10240/10240 [==============================] - 1s 69us/step - loss: 1.1004
- acc: 0.5379 - val_loss: 1.2396 - val_acc: 0.4449s - loss: 1.0980 - acc:
Epoch 73/80
10240/10240 [==============================] - 1s 71us/step - loss: 1.1024
- acc: 0.5311 - val_loss: 1.1952 - val_acc: 0.4766
Epoch 74/80
10240/10240 [==============================] - 1s 69us/step - loss: 1.1026
- acc: 0.5279 - val_loss: 1.2187 - val_acc: 0.4734
Epoch 75/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.0983
- acc: 0.5373 - val_loss: 1.2006 - val_acc: 0.4547
Epoch 76/80
10240/10240 [==============================] - 1s 70us/step - loss: 1.1071
- acc: 0.5298 - val_loss: 1.1993 - val_acc: 0.4727
Epoch 77/80
10240/10240 [==============================] - 1s 68us/step - loss: 1.1061
- acc: 0.5262 - val_loss: 1.2140 - val_acc: 0.4625
Epoch 78/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1023
- acc: 0.5316 - val_loss: 1.2088 - val_acc: 0.4781
Epoch 79/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.0978
- acc: 0.5294 - val_loss: 1.2037 - val_acc: 0.4785
Epoch 80/80
10240/10240 [==============================] - 1s 67us/step - loss: 1.1035
- acc: 0.5294 - val_loss: 1.1917 - val_acc: 0.4793
```

Out[58]:

```
<keras.callbacks.History at 0x1f487826ba8>
```

In [59]:

```
# Evaluate model
print('Evaluating model.')
eval_results = model_fc.evaluate(X_test,
                                  y_test,
                                  batch_size=user_model_batch)
print('Done.\n'
      'Test loss: {}\n'
      'Test acc: {}'.format(*eval_results))

test_scores.append({
    'model': 'connected model',
    'accuracy': eval_results[1]
})
```

```
Evaluating model.
2560/2560 [==============================] - 0s 47us/step
Done.
Test loss: 1.1917159155011177
Test acc: 0.479296875
```

Training each class separately with single layer GCN

In [60]:

```
d_emotion_models = {}
for emotion in range(num_labels):
    model_i = graph_convolution_one_layer_model(d_emotion_graphs[emotion])
    print(emotion, d_emotion_graphs[emotion].nnz)

    # Train model with emotion feature graph
    model_i.fit(X_train,
                        y_train,
                        batch_size=user_model_batch,
                        validation_data=validation_data,
                        epochs=epochs)

    d_emotion_models[emotion] = model_i
```

```
0 6396
Train on 10240 samples, validate on 2560 samples
Epoch 1/80
10240/10240 [==============================] - 6s 569us/step - loss: 1.348
2 - acc: 0.3524 - val_loss: 1.3057 - val_acc: 0.3859
Epoch 2/80
10240/10240 [==============================] - 5s 443us/step - loss: 1.254
5 - acc: 0.4275 - val_loss: 1.2619 - val_acc: 0.4344
Epoch 3/80
10240/10240 [==============================] - 5s 443us/step - loss: 1.220
5 - acc: 0.4528 - val_loss: 1.2168 - val_acc: 0.4637
Epoch 4/80
10240/10240 [==============================] - 4s 421us/step - loss: 1.204
4 - acc: 0.4639 - val_loss: 1.2485 - val_acc: 0.4414
Epoch 5/80
10240/10240 [==============================] - 4s 422us/step - loss: 1.196
2 - acc: 0.4703 - val_loss: 1.2721 - val_acc: 0.4523
Epoch 6/80
10240/10240 [==============================] - 4s 420us/step - loss: 1.192
5 - acc: 0.4752 - val_loss: 1.2030 - val_acc: 0.4582
Epoch 7/80
10240/10240 [==============================] - 5s 441us/step - loss: 1.184
5 - acc: 0.4787 - val_loss: 1.2115 - val_acc: 0.4656
Epoch 8/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.173
8 - acc: 0.4874 - val_loss: 1.1913 - val_acc: 0.4703
Epoch 9/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.173
8 - acc: 0.4895 - val_loss: 1.2267 - val_acc: 0.4633
Epoch 10/80
10240/10240 [==============================] - 5s 444us/step - loss: 1.167
5 - acc: 0.4879 - val_loss: 1.2095 - val_acc: 0.4648
Epoch 11/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.165
8 - acc: 0.4923 - val_loss: 1.1943 - val_acc: 0.4680
Epoch 12/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.164
5 - acc: 0.4897 - val_loss: 1.2237 - val_acc: 0.4582
Epoch 13/80
10240/10240 [==============================] - 4s 421us/step - loss: 1.159
1 - acc: 0.4954 - val_loss: 1.2168 - val_acc: 0.4617
Epoch 14/80
10240/10240 [==============================] - 5s 446us/step - loss: 1.160
0 - acc: 0.5006 - val_loss: 1.2021 - val_acc: 0.4777
Epoch 15/80
10240/10240 [==============================] - 4s 421us/step - loss: 1.158
7 - acc: 0.4956 - val_loss: 1.1982 - val_acc: 0.4629
Epoch 16/80
10240/10240 [==============================] - 4s 421us/step - loss: 1.157
1 - acc: 0.4985 - val_loss: 1.1895 - val_acc: 0.4840
Epoch 17/80
10240/10240 [==============================] - 5s 453us/step - loss: 1.151
3 - acc: 0.5014 - val_loss: 1.1827 - val_acc: 0.4805
Epoch 18/80
10240/10240 [==============================] - 4s 435us/step - loss: 1.152
3 - acc: 0.4990 - val_loss: 1.1977 - val_acc: 0.4664
Epoch 19/80
10240/10240 [==============================] - 4s 421us/step - loss: 1.143
1 - acc: 0.5091 - val_loss: 1.1949 - val_acc: 0.4688
Epoch 20/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.149
```

```
5 - acc: 0.5017 - val_loss: 1.2447 - val_acc: 0.4484
Epoch 21/80
10240/10240 [==============================] - 5s 441us/step - loss: 1.143
9 - acc: 0.5032 - val_loss: 1.1847 - val_acc: 0.4875
Epoch 22/80
10240/10240 [==============================] - 4s 421us/step - loss: 1.142
4 - acc: 0.5029 - val_loss: 1.1823 - val_acc: 0.4813
Epoch 23/80
10240/10240 [==============================] - 4s 425us/step - loss: 1.141
0 - acc: 0.5012 - val_loss: 1.1875 - val_acc: 0.4801
Epoch 24/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.139
2 - acc: 0.5072 - val_loss: 1.1911 - val_acc: 0.4883
Epoch 25/80
10240/10240 [==============================] - 5s 446us/step - loss: 1.139
9 - acc: 0.5080 - val_loss: 1.1969 - val_acc: 0.4730
Epoch 26/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.132
4 - acc: 0.5141 - val_loss: 1.1857 - val_acc: 0.4824
Epoch 27/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.136
5 - acc: 0.5116 - val_loss: 1.1733 - val_acc: 0.4914
Epoch 28/80
10240/10240 [==============================] - 4s 437us/step - loss: 1.131
5 - acc: 0.5067 - val_loss: 1.1955 - val_acc: 0.4777
Epoch 29/80
10240/10240 [==============================] - 5s 464us/step - loss: 1.131
3 - acc: 0.5103 - val_loss: 1.2245 - val_acc: 0.4625
Epoch 30/80
10240/10240 [==============================] - 5s 447us/step - loss: 1.128
2 - acc: 0.5123 - val_loss: 1.2216 - val_acc: 0.4703
Epoch 31/80
10240/10240 [==============================] - 4s 425us/step - loss: 1.128
1 - acc: 0.5083 - val_loss: 1.1808 - val_acc: 0.4719
Epoch 32/80
10240/10240 [==============================] - 5s 451us/step - loss: 1.132
8 - acc: 0.5110 - val_loss: 1.1954 - val_acc: 0.4793
Epoch 33/80
10240/10240 [==============================] - 4s 425us/step - loss: 1.124
3 - acc: 0.5112 - val_loss: 1.1742 - val_acc: 0.4863
Epoch 34/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.123
2 - acc: 0.5186 - val_loss: 1.1897 - val_acc: 0.4824
Epoch 35/80
10240/10240 [==============================] - 4s 431us/step - loss: 1.124
4 - acc: 0.5135 - val_loss: 1.2051 - val_acc: 0.4727
Epoch 36/80
10240/10240 [==============================] - 5s 448us/step - loss: 1.124
3 - acc: 0.5169 - val_loss: 1.1690 - val_acc: 0.4945
Epoch 37/80
10240/10240 [==============================] - 4s 426us/step - loss: 1.121
5 - acc: 0.5146 - val_loss: 1.1700 - val_acc: 0.4961
Epoch 38/80
10240/10240 [==============================] - 4s 425us/step - loss: 1.118
1 - acc: 0.5197 - val_loss: 1.1848 - val_acc: 0.4844
Epoch 39/80
10240/10240 [==============================] - 5s 451us/step - loss: 1.120
4 - acc: 0.5174 - val_loss: 1.1883 - val_acc: 0.4758
Epoch 40/80
10240/10240 [==============================] - 4s 430us/step - loss: 1.115
0 - acc: 0.5224 - val_loss: 1.1677 - val_acc: 0.4926
```

```
Epoch 41/80
10240/10240 [==============================] - 4s 426us/step - loss: 1.115
3 - acc: 0.5204 - val_loss: 1.1708 - val_acc: 0.4773
Epoch 42/80
10240/10240 [==============================] - 4s 427us/step - loss: 1.114
7 - acc: 0.5170 - val_loss: 1.1998 - val_acc: 0.4656
Epoch 43/80
10240/10240 [==============================] - 5s 448us/step - loss: 1.109
4 - acc: 0.5233 - val_loss: 1.1734 - val_acc: 0.4836
Epoch 44/80
10240/10240 [==============================] - 4s 428us/step - loss: 1.108
0 - acc: 0.5247 - val_loss: 1.2025 - val_acc: 0.4754
Epoch 45/80
10240/10240 [==============================] - 4s 426us/step - loss: 1.109
7 - acc: 0.5242 - val_loss: 1.1644 - val_acc: 0.4844
Epoch 46/80
10240/10240 [==============================] - 5s 447us/step - loss: 1.107
5 - acc: 0.5239 - val_loss: 1.1682 - val_acc: 0.4855
Epoch 47/80
10240/10240 [==============================] - 4s 428us/step - loss: 1.100
4 - acc: 0.5277 - val_loss: 1.1758 - val_acc: 0.4844
Epoch 48/80
10240/10240 [==============================] - 4s 428us/step - loss: 1.098
4 - acc: 0.5286 - val_loss: 1.2196 - val_acc: 0.4703
Epoch 49/80
10240/10240 [==============================] - 4s 426us/step - loss: 1.107
3 - acc: 0.5259 - val_loss: 1.1618 - val_acc: 0.4863
Epoch 50/80
10240/10240 [==============================] - 5s 452us/step - loss: 1.100
6 - acc: 0.5237 - val_loss: 1.1642 - val_acc: 0.4832
Epoch 51/80
10240/10240 [==============================] - 4s 428us/step - loss: 1.104
1 - acc: 0.5266 - val_loss: 1.1886 - val_acc: 0.4832
Epoch 52/80
10240/10240 [==============================] - 4s 428us/step - loss: 1.097
0 - acc: 0.5318 - val_loss: 1.1881 - val_acc: 0.4723
Epoch 53/80
10240/10240 [==============================] - 4s 418us/step - loss: 1.095
2 - acc: 0.5307 - val_loss: 1.1769 - val_acc: 0.4879
Epoch 54/80
10240/10240 [==============================] - 5s 441us/step - loss: 1.097
6 - acc: 0.5305 - val_loss: 1.1675 - val_acc: 0.4852
Epoch 55/80
10240/10240 [==============================] - 4s 420us/step - loss: 1.092
8 - acc: 0.5356 - val_loss: 1.1906 - val_acc: 0.4773
Epoch 56/80
10240/10240 [==============================] - 4s 431us/step - loss: 1.090
6 - acc: 0.5303 - val_loss: 1.1764 - val_acc: 0.4906
Epoch 57/80
10240/10240 [==============================] - 5s 443us/step - loss: 1.091
5 - acc: 0.5409 - val_loss: 1.1765 - val_acc: 0.4828
Epoch 58/80
10240/10240 [==============================] - 4s 420us/step - loss: 1.092
2 - acc: 0.5326 - val_loss: 1.1848 - val_acc: 0.4758
Epoch 59/80
10240/10240 [==============================] - 4s 415us/step - loss: 1.092
3 - acc: 0.5333 - val_loss: 1.1695 - val_acc: 0.4906
Epoch 60/80
10240/10240 [==============================] - 4s 415us/step - loss: 1.083
3 - acc: 0.5355 - val_loss: 1.1787 - val_acc: 0.4820
Epoch 61/80
```

```
10240/10240 [==============================] - 4s 438us/step - loss: 1.089
0 - acc: 0.5344 - val_loss: 1.1651 - val_acc: 0.4844
Epoch 62/80
10240/10240 [==============================] - 4s 417us/step - loss: 1.083
0 - acc: 0.5390 - val_loss: 1.1870 - val_acc: 0.4867
Epoch 63/80
10240/10240 [==============================] - 4s 414us/step - loss: 1.086
9 - acc: 0.5418 - val_loss: 1.1868 - val_acc: 0.4762
Epoch 64/80
10240/10240 [==============================] - 4s 430us/step - loss: 1.086
6 - acc: 0.5326 - val_loss: 1.1660 - val_acc: 0.4898
Epoch 65/80
10240/10240 [==============================] - 5s 458us/step - loss: 1.081
4 - acc: 0.5418 - val_loss: 1.1988 - val_acc: 0.4836
Epoch 66/80
10240/10240 [==============================] - 5s 447us/step - loss: 1.085
5 - acc: 0.5319 - val_loss: 1.1820 - val_acc: 0.4859
Epoch 67/80
10240/10240 [==============================] - 5s 451us/step - loss: 1.078
0 - acc: 0.5401 - val_loss: 1.1698 - val_acc: 0.4789
Epoch 68/80
10240/10240 [==============================] - 5s 455us/step - loss: 1.078
2 - acc: 0.5418 - val_loss: 1.1786 - val_acc: 0.4773
Epoch 69/80
10240/10240 [==============================] - 4s 428us/step - loss: 1.078
5 - acc: 0.5410 - val_loss: 1.1888 - val_acc: 0.4824
Epoch 70/80
10240/10240 [==============================] - 4s 428us/step - loss: 1.075
8 - acc: 0.5433 - val_loss: 1.1748 - val_acc: 0.4875
Epoch 71/80
10240/10240 [==============================] - 4s 433us/step - loss: 1.076
4 - acc: 0.5448 - val_loss: 1.1739 - val_acc: 0.4910
Epoch 72/80
10240/10240 [==============================] - 5s 449us/step - loss: 1.073
8 - acc: 0.5432 - val_loss: 1.1709 - val_acc: 0.4863
Epoch 73/80
10240/10240 [==============================] - 4s 428us/step - loss: 1.072
0 - acc: 0.5411 - val_loss: 1.1716 - val_acc: 0.4906
Epoch 74/80
10240/10240 [==============================] - 4s 430us/step - loss: 1.071
7 - acc: 0.5404 - val_loss: 1.1839 - val_acc: 0.4797
Epoch 75/80
10240/10240 [==============================] - 5s 448us/step - loss: 1.076
7 - acc: 0.5415 - val_loss: 1.1852 - val_acc: 0.4707
Epoch 76/80
10240/10240 [==============================] - 4s 428us/step - loss: 1.074
5 - acc: 0.5483 - val_loss: 1.1902 - val_acc: 0.4816
Epoch 77/80
10240/10240 [==============================] - 4s 428us/step - loss: 1.069
9 - acc: 0.5514 - val_loss: 1.1769 - val_acc: 0.4867
Epoch 78/80
10240/10240 [==============================] - 4s 428us/step - loss: 1.065
2 - acc: 0.5486 - val_loss: 1.1854 - val_acc: 0.4855
Epoch 79/80
10240/10240 [==============================] - 5s 451us/step - loss: 1.066
9 - acc: 0.5476 - val_loss: 1.1820 - val_acc: 0.4910
Epoch 80/80
10240/10240 [==============================] - 4s 426us/step - loss: 1.067
9 - acc: 0.5450 - val_loss: 1.1815 - val_acc: 0.4816
1 6396
Train on 10240 samples, validate on 2560 samples
```

```
Epoch 1/80
10240/10240 [==============================] - 6s 543us/step - loss: 1.330
1 - acc: 0.3713 - val_loss: 1.2828 - val_acc: 0.3922
Epoch 2/80
10240/10240 [==============================] - 5s 442us/step - loss: 1.226
9 - acc: 0.4474 - val_loss: 1.2215 - val_acc: 0.4621
Epoch 3/80
10240/10240 [==============================] - 4s 436us/step - loss: 1.209
4 - acc: 0.4570 - val_loss: 1.2172 - val_acc: 0.4605
Epoch 4/80
10240/10240 [==============================] - 4s 424us/step - loss: 1.194
3 - acc: 0.4729 - val_loss: 1.2048 - val_acc: 0.4613
Epoch 5/80
10240/10240 [==============================] - 4s 420us/step - loss: 1.185
3 - acc: 0.4782 - val_loss: 1.2405 - val_acc: 0.4414
Epoch 6/80
10240/10240 [==============================] - 5s 444us/step - loss: 1.181
1 - acc: 0.4809 - val_loss: 1.2179 - val_acc: 0.4555
Epoch 7/80
10240/10240 [==============================] - 4s 422us/step - loss: 1.175
6 - acc: 0.4798 - val_loss: 1.2531 - val_acc: 0.4305
Epoch 8/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.161
9 - acc: 0.4938 - val_loss: 1.2072 - val_acc: 0.4656
Epoch 9/80
10240/10240 [==============================] - 5s 450us/step - loss: 1.158
4 - acc: 0.4970 - val_loss: 1.2053 - val_acc: 0.4680
Epoch 10/80
10240/10240 [==============================] - 4s 425us/step - loss: 1.157
3 - acc: 0.4942 - val_loss: 1.1840 - val_acc: 0.4855
Epoch 11/80
10240/10240 [==============================] - 4s 425us/step - loss: 1.152
9 - acc: 0.4971 - val_loss: 1.1834 - val_acc: 0.4707
Epoch 12/80
10240/10240 [==============================] - 4s 424us/step - loss: 1.145
9 - acc: 0.5008 - val_loss: 1.1743 - val_acc: 0.4828
Epoch 13/80
10240/10240 [==============================] - 5s 446us/step - loss: 1.144
1 - acc: 0.5011 - val_loss: 1.1988 - val_acc: 0.4664
Epoch 14/80
10240/10240 [==============================] - 4s 422us/step - loss: 1.137
9 - acc: 0.5069 - val_loss: 1.1867 - val_acc: 0.4734
Epoch 15/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.134
4 - acc: 0.5104 - val_loss: 1.1718 - val_acc: 0.4879
Epoch 16/80
10240/10240 [==============================] - 4s 425us/step - loss: 1.130
8 - acc: 0.5099 - val_loss: 1.1871 - val_acc: 0.4836
Epoch 17/80
10240/10240 [==============================] - 5s 441us/step - loss: 1.134
3 - acc: 0.5045 - val_loss: 1.1693 - val_acc: 0.4777
Epoch 18/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.124
9 - acc: 0.5164 - val_loss: 1.2015 - val_acc: 0.4676
Epoch 19/80
10240/10240 [==============================] - 4s 420us/step - loss: 1.118
7 - acc: 0.5160 - val_loss: 1.1886 - val_acc: 0.4699
Epoch 20/80
10240/10240 [==============================] - 5s 455us/step - loss: 1.114
3 - acc: 0.5200 - val_loss: 1.1648 - val_acc: 0.4926
Epoch 21/80
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10240/10240 [==============================] - 4s 425us/step - loss: 1.112
7 - acc: 0.5141 - val_loss: 1.2114 - val_acc: 0.4746
Epoch 22/80
10240/10240 [==============================] - 4s 422us/step - loss: 1.118
8 - acc: 0.5201 - val_loss: 1.1624 - val_acc: 0.4844
Epoch 23/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.111
0 - acc: 0.5222 - val_loss: 1.1938 - val_acc: 0.4809
Epoch 24/80
10240/10240 [==============================] - 5s 448us/step - loss: 1.106
3 - acc: 0.5272 - val_loss: 1.1756 - val_acc: 0.4797
Epoch 25/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.104
7 - acc: 0.5259 - val_loss: 1.1707 - val_acc: 0.4859
Epoch 26/80
10240/10240 [==============================] - 4s 425us/step - loss: 1.097
0 - acc: 0.5338 - val_loss: 1.1780 - val_acc: 0.4859
Epoch 27/80
10240/10240 [==============================] - 4s 428us/step - loss: 1.098
6 - acc: 0.5274 - val_loss: 1.1767 - val_acc: 0.4785
Epoch 28/80
10240/10240 [==============================] - 5s 446us/step - loss: 1.092
9 - acc: 0.5307 - val_loss: 1.1684 - val_acc: 0.4973
Epoch 29/80
10240/10240 [==============================] - 4s 421us/step - loss: 1.091
2 - acc: 0.5328 - val_loss: 1.1701 - val_acc: 0.4832
Epoch 30/80
10240/10240 [==============================] - 5s 441us/step - loss: 1.091
6 - acc: 0.5313 - val_loss: 1.1744 - val_acc: 0.4902
Epoch 31/80
10240/10240 [==============================] - 5s 449us/step - loss: 1.086
4 - acc: 0.5373 - val_loss: 1.1856 - val_acc: 0.4887
Epoch 32/80
10240/10240 [==============================] - 4s 421us/step - loss: 1.083
1 - acc: 0.5384 - val_loss: 1.1746 - val_acc: 0.4844
Epoch 33/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.082
2 - acc: 0.5401 - val_loss: 1.1736 - val_acc: 0.4918
Epoch 34/80
10240/10240 [==============================] - 4s 424us/step - loss: 1.079
7 - acc: 0.5416 - val_loss: 1.1831 - val_acc: 0.4891
Epoch 35/80
10240/10240 [==============================] - 5s 447us/step - loss: 1.075
9 - acc: 0.5468 - val_loss: 1.1937 - val_acc: 0.4840
Epoch 36/80
10240/10240 [==============================] - 4s 425us/step - loss: 1.075
4 - acc: 0.5460 - val_loss: 1.1810 - val_acc: 0.4883
Epoch 37/80
10240/10240 [==============================] - 4s 430us/step - loss: 1.072
6 - acc: 0.5439 - val_loss: 1.1655 - val_acc: 0.4914
Epoch 38/80
10240/10240 [==============================] - 4s 421us/step - loss: 1.073
8 - acc: 0.5428 - val_loss: 1.1715 - val_acc: 0.4887
Epoch 39/80
10240/10240 [==============================] - 4s 418us/step - loss: 1.070
0 - acc: 0.5509 - val_loss: 1.1744 - val_acc: 0.4867
Epoch 40/80
10240/10240 [==============================] - 4s 407us/step - loss: 1.064
3 - acc: 0.5492 - val_loss: 1.2104 - val_acc: 0.4672
Epoch 41/80
10240/10240 [==============================] - 4s 410us/step - loss: 1.064
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3 - acc: 0.5498 - val_loss: 1.1776 - val_acc: 0.4852
Epoch 42/80
10240/10240 [==============================] - 5s 460us/step - loss: 1.061
6 - acc: 0.5525 - val_loss: 1.1961 - val_acc: 0.4785
Epoch 43/80
10240/10240 [==============================] - 5s 444us/step - loss: 1.059
9 - acc: 0.5568 - val_loss: 1.1831 - val_acc: 0.4887
Epoch 44/80
10240/10240 [==============================] - 4s 419us/step - loss: 1.055
4 - acc: 0.5547 - val_loss: 1.1762 - val_acc: 0.4879
Epoch 45/80
10240/10240 [==============================] - 4s 410us/step - loss: 1.058
2 - acc: 0.5542 - val_loss: 1.1946 - val_acc: 0.4832
Epoch 46/80
10240/10240 [==============================] - 4s 431us/step - loss: 1.057
5 - acc: 0.5544 - val_loss: 1.2043 - val_acc: 0.4793
Epoch 47/80
10240/10240 [==============================] - 4s 410us/step - loss: 1.054
6 - acc: 0.5600 - val_loss: 1.1839 - val_acc: 0.4938
Epoch 48/80
10240/10240 [==============================] - 4s 408us/step - loss: 1.049
4 - acc: 0.5616 - val_loss: 1.2117 - val_acc: 0.4758
Epoch 49/80
10240/10240 [==============================] - 4s 413us/step - loss: 1.048
3 - acc: 0.5619 - val_loss: 1.1847 - val_acc: 0.4852
Epoch 50/80
10240/10240 [==============================] - 4s 428us/step - loss: 1.049
1 - acc: 0.5645 - val_loss: 1.2154 - val_acc: 0.4770
Epoch 51/80
10240/10240 [==============================] - 4s 410us/step - loss: 1.047
1 - acc: 0.5626 - val_loss: 1.1833 - val_acc: 0.4855
Epoch 52/80
10240/10240 [==============================] - 4s 410us/step - loss: 1.043
4 - acc: 0.5636 - val_loss: 1.1987 - val_acc: 0.4777
Epoch 53/80
10240/10240 [==============================] - 4s 432us/step - loss: 1.042
6 - acc: 0.5643 - val_loss: 1.1843 - val_acc: 0.4852
Epoch 54/80
10240/10240 [==============================] - 4s 412us/step - loss: 1.044
1 - acc: 0.5677 - val_loss: 1.1994 - val_acc: 0.4898
Epoch 55/80
10240/10240 [==============================] - 4s 421us/step - loss: 1.041
9 - acc: 0.5639 - val_loss: 1.1971 - val_acc: 0.4820
Epoch 56/80
10240/10240 [==============================] - 4s 419us/step - loss: 1.036
6 - acc: 0.5667 - val_loss: 1.1845 - val_acc: 0.4840
Epoch 57/80
10240/10240 [==============================] - 4s 431us/step - loss: 1.038
1 - acc: 0.5668 - val_loss: 1.1852 - val_acc: 0.4809
Epoch 58/80
10240/10240 [==============================] - 4s 425us/step - loss: 1.032
1 - acc: 0.5716 - val_loss: 1.2057 - val_acc: 0.4887
Epoch 59/80
10240/10240 [==============================] - 4s 412us/step - loss: 1.036
9 - acc: 0.5709 - val_loss: 1.2246 - val_acc: 0.4754
Epoch 60/80
10240/10240 [==============================] - 4s 409us/step - loss: 1.029
9 - acc: 0.5753 - val_loss: 1.1899 - val_acc: 0.4867
Epoch 61/80
10240/10240 [==============================] - 4s 433us/step - loss: 1.032
5 - acc: 0.5691 - val_loss: 1.2100 - val_acc: 0.4738
```

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Epoch 62/80
10240/10240 [==============================] - 4s 412us/step - loss: 1.029
7 - acc: 0.5714 - val_loss: 1.2158 - val_acc: 0.4742
Epoch 63/80
10240/10240 [==============================] - 4s 410us/step - loss: 1.026
8 - acc: 0.5752 - val_loss: 1.2046 - val_acc: 0.4848
Epoch 64/80
10240/10240 [==============================] - 4s 419us/step - loss: 1.023
3 - acc: 0.5756 - val_loss: 1.2096 - val_acc: 0.4711
Epoch 65/80
10240/10240 [==============================] - 4s 424us/step - loss: 1.024
6 - acc: 0.5748 - val_loss: 1.1967 - val_acc: 0.4875
Epoch 66/80
10240/10240 [==============================] - 4s 408us/step - loss: 1.023
8 - acc: 0.5773 - val_loss: 1.1910 - val_acc: 0.4875
Epoch 67/80
10240/10240 [==============================] - 4s 412us/step - loss: 1.020
2 - acc: 0.5792 - val_loss: 1.2057 - val_acc: 0.4898
Epoch 68/80
10240/10240 [==============================] - 4s 431us/step - loss: 1.020
0 - acc: 0.5763 - val_loss: 1.2613 - val_acc: 0.4652
Epoch 69/80
10240/10240 [==============================] - 4s 413us/step - loss: 1.018
1 - acc: 0.5760 - val_loss: 1.2042 - val_acc: 0.4820
Epoch 70/80
10240/10240 [==============================] - 4s 412us/step - loss: 1.019
3 - acc: 0.5813 - val_loss: 1.2254 - val_acc: 0.4777
Epoch 71/80
10240/10240 [==============================] - 4s 410us/step - loss: 1.018
0 - acc: 0.5822 - val_loss: 1.2229 - val_acc: 0.4793
Epoch 72/80
10240/10240 [==============================] - 4s 433us/step - loss: 1.010
9 - acc: 0.5829 - val_loss: 1.2033 - val_acc: 0.4844
Epoch 73/80
10240/10240 [==============================] - 4s 408us/step - loss: 1.014
7 - acc: 0.5798 - val_loss: 1.2088 - val_acc: 0.4828
Epoch 74/80
10240/10240 [==============================] - 4s 412us/step - loss: 1.011
0 - acc: 0.5800 - val_loss: 1.2045 - val_acc: 0.4867
Epoch 75/80
10240/10240 [==============================] - 4s 412us/step - loss: 1.008
6 - acc: 0.5882 - val_loss: 1.2058 - val_acc: 0.4813
Epoch 76/80
10240/10240 [==============================] - 4s 435us/step - loss: 1.006
2 - acc: 0.5851 - val_loss: 1.2150 - val_acc: 0.4770
Epoch 77/80
10240/10240 [==============================] - 4s 413us/step - loss: 1.009
1 - acc: 0.5839 - val_loss: 1.2123 - val_acc: 0.4891
Epoch 78/80
10240/10240 [==============================] - 4s 412us/step - loss: 1.006
2 - acc: 0.5864 - val_loss: 1.2169 - val_acc: 0.4844
Epoch 79/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.007
7 - acc: 0.5880 - val_loss: 1.2126 - val_acc: 0.4832
Epoch 80/80
10240/10240 [==============================] - 4s 424us/step - loss: 1.007
1 - acc: 0.5890 - val_loss: 1.2232 - val_acc: 0.4797
2 6396
Train on 10240 samples, validate on 2560 samples
Epoch 1/80
10240/10240 [==============================] - 5s 532us/step - loss: 1.343
```

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5 - acc: 0.3607 - val_loss: 1.2777 - val_acc: 0.4121
Epoch 2/80
10240/10240 [==============================] - 4s 417us/step - loss: 1.238
3 - acc: 0.4383 - val_loss: 1.2324 - val_acc: 0.4465
Epoch 3/80
10240/10240 [==============================] - 5s 441us/step - loss: 1.210
6 - acc: 0.4576 - val_loss: 1.2159 - val_acc: 0.4543
Epoch 4/80
10240/10240 [==============================] - 4s 417us/step - loss: 1.197
5 - acc: 0.4754 - val_loss: 1.2500 - val_acc: 0.4559
Epoch 5/80
10240/10240 [==============================] - 4s 423us/step - loss: 1.189
6 - acc: 0.4724 - val_loss: 1.2193 - val_acc: 0.4484
Epoch 6/80
10240/10240 [==============================] - 5s 440us/step - loss: 1.186
0 - acc: 0.4752 - val_loss: 1.2262 - val_acc: 0.4492
Epoch 7/80
10240/10240 [==============================] - 4s 430us/step - loss: 1.183
9 - acc: 0.4797 - val_loss: 1.2103 - val_acc: 0.4551
Epoch 8/80
10240/10240 [==============================] - 4s 420us/step - loss: 1.174
8 - acc: 0.4929 - val_loss: 1.2135 - val_acc: 0.4551
Epoch 9/80
10240/10240 [==============================] - 4s 417us/step - loss: 1.168
1 - acc: 0.4885 - val_loss: 1.2322 - val_acc: 0.4586
Epoch 10/80
10240/10240 [==============================] - 5s 439us/step - loss: 1.173
5 - acc: 0.4887 - val_loss: 1.2012 - val_acc: 0.4734
Epoch 11/80
10240/10240 [==============================] - 4s 418us/step - loss: 1.164
3 - acc: 0.4870 - val_loss: 1.1900 - val_acc: 0.4738
Epoch 12/80
10240/10240 [==============================] - 4s 420us/step - loss: 1.162
8 - acc: 0.4905 - val_loss: 1.1945 - val_acc: 0.4609
Epoch 13/80
10240/10240 [==============================] - 4s 417us/step - loss: 1.154
1 - acc: 0.4938 - val_loss: 1.1940 - val_acc: 0.4664
Epoch 14/80
10240/10240 [==============================] - 4s 439us/step - loss: 1.152
2 - acc: 0.4956 - val_loss: 1.1916 - val_acc: 0.4727
Epoch 15/80
10240/10240 [==============================] - 4s 418us/step - loss: 1.148
3 - acc: 0.5006 - val_loss: 1.1977 - val_acc: 0.4746
Epoch 16/80
10240/10240 [==============================] - 4s 416us/step - loss: 1.143
7 - acc: 0.5053 - val_loss: 1.1809 - val_acc: 0.4805
Epoch 17/80
10240/10240 [==============================] - 4s 416us/step - loss: 1.137
6 - acc: 0.5078 - val_loss: 1.1777 - val_acc: 0.4789
Epoch 18/80
10240/10240 [==============================] - 4s 435us/step - loss: 1.141
0 - acc: 0.5079 - val_loss: 1.1737 - val_acc: 0.4820
Epoch 19/80
10240/10240 [==============================] - 4s 413us/step - loss: 1.130
4 - acc: 0.5099 - val_loss: 1.1825 - val_acc: 0.4797
Epoch 20/80
10240/10240 [==============================] - 4s 415us/step - loss: 1.131
7 - acc: 0.5112 - val_loss: 1.1893 - val_acc: 0.4820
Epoch 21/80
10240/10240 [==============================] - 4s 434us/step - loss: 1.130
6 - acc: 0.5131 - val_loss: 1.1814 - val_acc: 0.4766
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Epoch 22/80
10240/10240 [==============================] - 4s 415us/step - loss: 1.128
3 - acc: 0.5146 - val_loss: 1.1689 - val_acc: 0.4746
Epoch 23/80
10240/10240 [==============================] - 4s 415us/step - loss: 1.124
1 - acc: 0.5153 - val_loss: 1.1887 - val_acc: 0.4785
Epoch 24/80
10240/10240 [==============================] - 4s 415us/step - loss: 1.123
7 - acc: 0.5106 - val_loss: 1.1855 - val_acc: 0.4727
Epoch 25/80
10240/10240 [==============================] - 4s 434us/step - loss: 1.122
4 - acc: 0.5203 - val_loss: 1.1900 - val_acc: 0.4727
Epoch 26/80
10240/10240 [==============================] - 4s 415us/step - loss: 1.118
9 - acc: 0.5233 - val_loss: 1.1767 - val_acc: 0.4797
Epoch 27/80
10240/10240 [==============================] - 4s 416us/step - loss: 1.115
4 - acc: 0.5213 - val_loss: 1.1690 - val_acc: 0.4770
Epoch 28/80
10240/10240 [==============================] - 4s 417us/step - loss: 1.109
7 - acc: 0.5256 - val_loss: 1.1801 - val_acc: 0.4809
Epoch 29/80
10240/10240 [==============================] - 5s 529us/step - loss: 1.112
1 - acc: 0.5177 - val_loss: 1.1714 - val_acc: 0.4770
Epoch 30/80
10240/10240 [==============================] - 4s 432us/step - loss: 1.112
6 - acc: 0.5256 - val_loss: 1.1976 - val_acc: 0.4805
Epoch 31/80
10240/10240 [==============================] - 5s 467us/step - loss: 1.107
4 - acc: 0.5239 - val_loss: 1.1885 - val_acc: 0.4770
Epoch 32/80
10240/10240 [==============================] - 4s 439us/step - loss: 1.100
0 - acc: 0.5299 - val_loss: 1.1987 - val_acc: 0.4719
Epoch 33/80
10240/10240 [==============================] - 4s 431us/step - loss: 1.106
3 - acc: 0.5248 - val_loss: 1.1989 - val_acc: 0.4680
Epoch 34/80
10240/10240 [==============================] - 4s 415us/step - loss: 1.098
6 - acc: 0.5307 - val_loss: 1.1761 - val_acc: 0.4813
Epoch 35/80
10240/10240 [==============================] - 4s 415us/step - loss: 1.093
9 - acc: 0.5321 - val_loss: 1.1758 - val_acc: 0.4805
Epoch 36/80
10240/10240 [==============================] - 4s 438us/step - loss: 1.090
5 - acc: 0.5301 - val_loss: 1.1754 - val_acc: 0.4809
Epoch 37/80
10240/10240 [==============================] - 4s 415us/step - loss: 1.088
9 - acc: 0.5396 - val_loss: 1.1695 - val_acc: 0.4922
Epoch 38/80
10240/10240 [==============================] - 4s 418us/step - loss: 1.091
2 - acc: 0.5380 - val_loss: 1.1792 - val_acc: 0.4848
Epoch 39/80
10240/10240 [==============================] - 4s 432us/step - loss: 1.087
2 - acc: 0.5326 - val_loss: 1.1675 - val_acc: 0.4961
Epoch 40/80
10240/10240 [==============================] - 4s 422us/step - loss: 1.088
0 - acc: 0.5387 - val_loss: 1.1873 - val_acc: 0.4793
Epoch 41/80
10240/10240 [==============================] - 4s 415us/step - loss: 1.084
8 - acc: 0.5422 - val_loss: 1.1646 - val_acc: 0.4801
Epoch 42/80
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10240/10240 [==============================] - 4s 415us/step - loss: 1.086
6 - acc: 0.5392 - val_loss: 1.1805 - val_acc: 0.4813
Epoch 43/80
10240/10240 [==============================] - 4s 439us/step - loss: 1.081
4 - acc: 0.5425 - val_loss: 1.1711 - val_acc: 0.4797
Epoch 44/80
10240/10240 [==============================] - 4s 418us/step - loss: 1.078
6 - acc: 0.5450 - val_loss: 1.1697 - val_acc: 0.4867
Epoch 45/80
10240/10240 [==============================] - 4s 417us/step - loss: 1.073
2 - acc: 0.5467 - val_loss: 1.1642 - val_acc: 0.4887
Epoch 46/80
10240/10240 [==============================] - 4s 416us/step - loss: 1.073
1 - acc: 0.5432 - val_loss: 1.1757 - val_acc: 0.4945
Epoch 47/80
10240/10240 [==============================] - 4s 437us/step - loss: 1.072
2 - acc: 0.5487 - val_loss: 1.1654 - val_acc: 0.4902
Epoch 48/80
10240/10240 [==============================] - 4s 417us/step - loss: 1.068
8 - acc: 0.5519 - val_loss: 1.1751 - val_acc: 0.4859
Epoch 49/80
10240/10240 [==============================] - 4s 417us/step - loss: 1.072
7 - acc: 0.5513 - val_loss: 1.1712 - val_acc: 0.4906
Epoch 50/80
10240/10240 [==============================] - 4s 426us/step - loss: 1.064
9 - acc: 0.5523 - val_loss: 1.1777 - val_acc: 0.4789
Epoch 51/80
10240/10240 [==============================] - 5s 474us/step - loss: 1.064
5 - acc: 0.5514 - val_loss: 1.1697 - val_acc: 0.4848
Epoch 52/80
10240/10240 [==============================] - 5s 441us/step - loss: 1.059
2 - acc: 0.5528 - val_loss: 1.1711 - val_acc: 0.4820
Epoch 53/80
10240/10240 [==============================] - 4s 433us/step - loss: 1.059
1 - acc: 0.5535 - val_loss: 1.1874 - val_acc: 0.4871
Epoch 54/80
10240/10240 [==============================] - 5s 452us/step - loss: 1.058
8 - acc: 0.5539 - val_loss: 1.1874 - val_acc: 0.4809
Epoch 55/80
10240/10240 [==============================] - 4s 427us/step - loss: 1.056
6 - acc: 0.5544 - val_loss: 1.1933 - val_acc: 0.4762
Epoch 56/80
10240/10240 [==============================] - 4s 433us/step - loss: 1.051
9 - acc: 0.5630 - val_loss: 1.1933 - val_acc: 0.4836
Epoch 57/80
10240/10240 [==============================] - 4s 434us/step - loss: 1.053
3 - acc: 0.5600 - val_loss: 1.1723 - val_acc: 0.4844
Epoch 58/80
10240/10240 [==============================] - 5s 454us/step - loss: 1.045
4 - acc: 0.5645 - val_loss: 1.1890 - val_acc: 0.4793
Epoch 59/80
10240/10240 [==============================] - 4s 431us/step - loss: 1.049
6 - acc: 0.5620 - val_loss: 1.1815 - val_acc: 0.4875
Epoch 60/80
10240/10240 [==============================] - 5s 454us/step - loss: 1.043
2 - acc: 0.5650 - val_loss: 1.1854 - val_acc: 0.4836
Epoch 61/80
10240/10240 [==============================] - 5s 464us/step - loss: 1.040
2 - acc: 0.5689 - val_loss: 1.1773 - val_acc: 0.4977
Epoch 62/80
10240/10240 [==============================] - 4s 433us/step - loss: 1.042
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0 - acc: 0.5682 - val_loss: 1.1794 - val_acc: 0.4898
Epoch 63/80
10240/10240 [==============================] - 4s 431us/step - loss: 1.039
7 - acc: 0.5651 - val_loss: 1.1861 - val_acc: 0.4852
Epoch 64/80
10240/10240 [==============================] - 4s 430us/step - loss: 1.036
6 - acc: 0.5715 - val_loss: 1.1828 - val_acc: 0.4848
Epoch 65/80
10240/10240 [==============================] - 5s 449us/step - loss: 1.035
6 - acc: 0.5717 - val_loss: 1.1859 - val_acc: 0.4820
Epoch 66/80
10240/10240 [==============================] - 4s 435us/step - loss: 1.035
5 - acc: 0.5716 - val_loss: 1.1802 - val_acc: 0.4918
Epoch 67/80
10240/10240 [==============================] - 4s 435us/step - loss: 1.030
6 - acc: 0.5767 - val_loss: 1.2002 - val_acc: 0.4809
Epoch 68/80
10240/10240 [==============================] - 5s 454us/step - loss: 1.032
2 - acc: 0.5711 - val_loss: 1.1934 - val_acc: 0.4910
Epoch 69/80
10240/10240 [==============================] - 4s 430us/step - loss: 1.029
2 - acc: 0.5745 - val_loss: 1.1871 - val_acc: 0.4914
Epoch 70/80
10240/10240 [==============================] - 4s 433us/step - loss: 1.023
2 - acc: 0.5782 - val_loss: 1.1841 - val_acc: 0.4836
Epoch 71/80
10240/10240 [==============================] - 4s 433us/step - loss: 1.022
8 - acc: 0.5742 - val_loss: 1.2052 - val_acc: 0.4875
Epoch 72/80
10240/10240 [==============================] - 5s 451us/step - loss: 1.025
7 - acc: 0.5745 - val_loss: 1.1868 - val_acc: 0.4918
Epoch 73/80
10240/10240 [==============================] - 4s 428us/step - loss: 1.019
9 - acc: 0.5769 - val_loss: 1.1855 - val_acc: 0.4840
Epoch 74/80
10240/10240 [==============================] - 4s 433us/step - loss: 1.023
2 - acc: 0.5768 - val_loss: 1.1824 - val_acc: 0.4926
Epoch 75/80
10240/10240 [==============================] - 4s 436us/step - loss: 1.025
2 - acc: 0.5759 - val_loss: 1.1926 - val_acc: 0.4852
Epoch 76/80
10240/10240 [==============================] - 4s 419us/step - loss: 1.019
4 - acc: 0.5793 - val_loss: 1.1999 - val_acc: 0.4801
Epoch 77/80
10240/10240 [==============================] - 4s 415us/step - loss: 1.016
9 - acc: 0.5797 - val_loss: 1.2022 - val_acc: 0.4848
Epoch 78/80
10240/10240 [==============================] - 4s 415us/step - loss: 1.012
9 - acc: 0.5810 - val_loss: 1.1850 - val_acc: 0.4891
Epoch 79/80
10240/10240 [==============================] - 4s 435us/step - loss: 1.013
1 - acc: 0.5820 - val_loss: 1.2168 - val_acc: 0.4797
Epoch 80/80
10240/10240 [==============================] - 4s 413us/step - loss: 1.013
7 - acc: 0.5837 - val_loss: 1.2359 - val_acc: 0.4742
3 6396
Train on 10240 samples, validate on 2560 samples
Epoch 1/80
10240/10240 [==============================] - 6s 540us/step - loss: 1.340
9 - acc: 0.3711 - val_loss: 1.2470 - val_acc: 0.4371
Epoch 2/80
```

```
10240/10240 [==============================] - 5s 458us/step - loss: 1.236
9 - acc: 0.4510 - val_loss: 1.2437 - val_acc: 0.4398
Epoch 3/80
10240/10240 [==============================] - 5s 443us/step - loss: 1.206
0 - acc: 0.4647 - val_loss: 1.2245 - val_acc: 0.4508
Epoch 4/80
10240/10240 [==============================] - 5s 441us/step - loss: 1.199
3 - acc: 0.4707 - val_loss: 1.2614 - val_acc: 0.4117
Epoch 5/80
10240/10240 [==============================] - 4s 438us/step - loss: 1.191
7 - acc: 0.4775 - val_loss: 1.2296 - val_acc: 0.4523
Epoch 6/80
10240/10240 [==============================] - 5s 469us/step - loss: 1.186
6 - acc: 0.4787 - val_loss: 1.1977 - val_acc: 0.4746
Epoch 7/80
10240/10240 [==============================] - 5s 452us/step - loss: 1.183
3 - acc: 0.4781 - val_loss: 1.2070 - val_acc: 0.4535
Epoch 8/80
10240/10240 [==============================] - 5s 441us/step - loss: 1.171
9 - acc: 0.4859 - val_loss: 1.2196 - val_acc: 0.4594
Epoch 9/80
10240/10240 [==============================] - 5s 462us/step - loss: 1.171
7 - acc: 0.4875 - val_loss: 1.2037 - val_acc: 0.4559
Epoch 10/80
10240/10240 [==============================] - 5s 443us/step - loss: 1.163
5 - acc: 0.4931 - val_loss: 1.1809 - val_acc: 0.4801
Epoch 11/80
10240/10240 [==============================] - 5s 442us/step - loss: 1.159
4 - acc: 0.4898 - val_loss: 1.1854 - val_acc: 0.472388 - acc: 0.4
Epoch 12/80
10240/10240 [==============================] - 5s 456us/step - loss: 1.152
3 - acc: 0.5008 - val_loss: 1.1909 - val_acc: 0.4711
Epoch 13/80
10240/10240 [==============================] - 5s 491us/step - loss: 1.152
3 - acc: 0.4990 - val_loss: 1.1772 - val_acc: 0.4840
Epoch 14/80
10240/10240 [==============================] - 5s 454us/step - loss: 1.149
4 - acc: 0.5021 - val_loss: 1.2001 - val_acc: 0.4680
Epoch 15/80
10240/10240 [==============================] - 5s 450us/step - loss: 1.145
1 - acc: 0.4986 - val_loss: 1.1944 - val_acc: 0.4727
Epoch 16/80
10240/10240 [==============================] - 5s 475us/step - loss: 1.140
2 - acc: 0.5078 - val_loss: 1.1975 - val_acc: 0.4773
Epoch 17/80
10240/10240 [==============================] - 5s 452us/step - loss: 1.138
6 - acc: 0.5101 - val_loss: 1.2033 - val_acc: 0.4668
Epoch 18/80
10240/10240 [==============================] - 5s 454us/step - loss: 1.133
8 - acc: 0.5060 - val_loss: 1.2065 - val_acc: 0.4734
Epoch 19/80
10240/10240 [==============================] - 5s 451us/step - loss: 1.132
9 - acc: 0.5122 - val_loss: 1.2111 - val_acc: 0.4656
Epoch 20/80
10240/10240 [==============================] - 5s 474us/step - loss: 1.124
4 - acc: 0.5160 - val_loss: 1.1710 - val_acc: 0.4715
Epoch 21/80
10240/10240 [==============================] - 5s 452us/step - loss: 1.123
5 - acc: 0.5188 - val_loss: 1.1772 - val_acc: 0.4773
Epoch 22/80
10240/10240 [==============================] - 5s 454us/step - loss: 1.124
```

```
7 - acc: 0.5160 - val_loss: 1.1951 - val_acc: 0.4695
Epoch 23/80
10240/10240 [==============================] - 5s 475us/step - loss: 1.124
1 - acc: 0.5136 - val_loss: 1.2355 - val_acc: 0.4539
Epoch 24/80
10240/10240 [==============================] - 5s 453us/step - loss: 1.122
9 - acc: 0.5121 - val_loss: 1.2158 - val_acc: 0.4535
Epoch 25/80
10240/10240 [==============================] - 5s 451us/step - loss: 1.112
0 - acc: 0.5222 - val_loss: 1.1791 - val_acc: 0.4785
Epoch 26/80
10240/10240 [==============================] - 5s 473us/step - loss: 1.114
7 - acc: 0.5221 - val_loss: 1.1712 - val_acc: 0.4887
Epoch 27/80
10240/10240 [==============================] - 5s 465us/step - loss: 1.112
0 - acc: 0.5230 - val_loss: 1.1887 - val_acc: 0.4789
Epoch 28/80
10240/10240 [==============================] - 5s 454us/step - loss: 1.113
3 - acc: 0.5206 - val_loss: 1.2175 - val_acc: 0.4727
Epoch 29/80
10240/10240 [==============================] - 5s 453us/step - loss: 1.108
3 - acc: 0.5248 - val_loss: 1.1846 - val_acc: 0.4750
Epoch 30/80
10240/10240 [==============================] - 5s 473us/step - loss: 1.110
4 - acc: 0.5173 - val_loss: 1.2130 - val_acc: 0.4738
Epoch 31/80
10240/10240 [==============================] - 5s 451us/step - loss: 1.102
3 - acc: 0.5324 - val_loss: 1.1726 - val_acc: 0.4813
Epoch 32/80
10240/10240 [==============================] - 5s 469us/step - loss: 1.101
4 - acc: 0.5303 - val_loss: 1.2153 - val_acc: 0.4652
Epoch 33/80
10240/10240 [==============================] - 5s 475us/step - loss: 1.094
0 - acc: 0.5327 - val_loss: 1.1677 - val_acc: 0.4828
Epoch 34/80
10240/10240 [==============================] - 5s 451us/step - loss: 1.095
6 - acc: 0.5333 - val_loss: 1.1849 - val_acc: 0.4758
Epoch 35/80
10240/10240 [==============================] - 5s 454us/step - loss: 1.090
3 - acc: 0.5383 - val_loss: 1.1882 - val_acc: 0.4770
Epoch 36/80
10240/10240 [==============================] - 5s 458us/step - loss: 1.090
0 - acc: 0.5372 - val_loss: 1.1764 - val_acc: 0.4766
Epoch 37/80
10240/10240 [==============================] - 5s 473us/step - loss: 1.092
2 - acc: 0.5330 - val_loss: 1.1775 - val_acc: 0.4859
Epoch 38/80
10240/10240 [==============================] - 5s 454us/step - loss: 1.088
6 - acc: 0.5344 - val_loss: 1.1870 - val_acc: 0.4719
Epoch 39/80
10240/10240 [==============================] - 5s 456us/step - loss: 1.085
2 - acc: 0.5356 - val_loss: 1.1886 - val_acc: 0.4828
Epoch 40/80
10240/10240 [==============================] - 5s 477us/step - loss: 1.087
7 - acc: 0.5398 - val_loss: 1.1727 - val_acc: 0.4887
Epoch 41/80
10240/10240 [==============================] - 5s 452us/step - loss: 1.081
0 - acc: 0.5422 - val_loss: 1.1878 - val_acc: 0.4777
Epoch 42/80
10240/10240 [==============================] - 5s 455us/step - loss: 1.076
8 - acc: 0.5433 - val_loss: 1.1735 - val_acc: 0.4871
```

```
Epoch 43/80
10240/10240 [==============================] - 5s 478us/step - loss: 1.082
5 - acc: 0.5408 - val_loss: 1.1796 - val_acc: 0.4832
Epoch 44/80
10240/10240 [==============================] - 5s 451us/step - loss: 1.078
2 - acc: 0.5434 - val_loss: 1.2104 - val_acc: 0.4758
Epoch 45/80
10240/10240 [==============================] - 5s 456us/step - loss: 1.078
4 - acc: 0.5429 - val_loss: 1.1822 - val_acc: 0.4695
Epoch 46/80
10240/10240 [==============================] - 5s 456us/step - loss: 1.077
1 - acc: 0.5483 - val_loss: 1.1937 - val_acc: 0.4785
Epoch 47/80
10240/10240 [==============================] - 5s 477us/step - loss: 1.072
4 - acc: 0.5420 - val_loss: 1.1876 - val_acc: 0.4828
Epoch 48/80
10240/10240 [==============================] - 5s 456us/step - loss: 1.074
9 - acc: 0.5457 - val_loss: 1.2113 - val_acc: 0.4629
Epoch 49/80
10240/10240 [==============================] - 5s 454us/step - loss: 1.071
5 - acc: 0.5479 - val_loss: 1.1734 - val_acc: 0.4859
Epoch 50/80
10240/10240 [==============================] - 5s 478us/step - loss: 1.070
8 - acc: 0.5483 - val_loss: 1.1688 - val_acc: 0.4867
Epoch 51/80
10240/10240 [==============================] - 5s 457us/step - loss: 1.067
5 - acc: 0.5516 - val_loss: 1.1822 - val_acc: 0.4832
Epoch 52/80
10240/10240 [==============================] - 5s 457us/step - loss: 1.068
3 - acc: 0.5487 - val_loss: 1.1701 - val_acc: 0.4918
Epoch 53/80
10240/10240 [==============================] - 5s 448us/step - loss: 1.067
7 - acc: 0.5494 - val_loss: 1.1867 - val_acc: 0.4801
Epoch 54/80
10240/10240 [==============================] - 5s 454us/step - loss: 1.066
4 - acc: 0.5560 - val_loss: 1.1754 - val_acc: 0.4875
Epoch 55/80
10240/10240 [==============================] - 5s 440us/step - loss: 1.062
8 - acc: 0.5539 - val_loss: 1.1753 - val_acc: 0.4820
Epoch 56/80
10240/10240 [==============================] - 5s 441us/step - loss: 1.061
0 - acc: 0.5553 - val_loss: 1.1850 - val_acc: 0.4832- loss: 1.0602
Epoch 57/80
10240/10240 [==============================] - 5s 462us/step - loss: 1.059
3 - acc: 0.5563 - val_loss: 1.1938 - val_acc: 0.4832
Epoch 58/80
10240/10240 [==============================] - 5s 455us/step - loss: 1.066
8 - acc: 0.5488 - val_loss: 1.2381 - val_acc: 0.4727
Epoch 59/80
10240/10240 [==============================] - 5s 440us/step - loss: 1.058
3 - acc: 0.5582 - val_loss: 1.1804 - val_acc: 0.4887
Epoch 60/80
10240/10240 [==============================] - 5s 452us/step - loss: 1.051
2 - acc: 0.5610 - val_loss: 1.2688 - val_acc: 0.4590
Epoch 61/80
10240/10240 [==============================] - 5s 453us/step - loss: 1.054
1 - acc: 0.5600 - val_loss: 1.1988 - val_acc: 0.4832
Epoch 62/80
10240/10240 [==============================] - 5s 441us/step - loss: 1.052
5 - acc: 0.5607 - val_loss: 1.2176 - val_acc: 0.4680
Epoch 63/80
```

```
10240/10240 [==============================] - 5s 441us/step - loss: 1.052
7 - acc: 0.5604 - val_loss: 1.1700 - val_acc: 0.4879
Epoch 64/80
10240/10240 [==============================] - 5s 461us/step - loss: 1.055
1 - acc: 0.5519 - val_loss: 1.2035 - val_acc: 0.4832
Epoch 65/80
10240/10240 [==============================] - 5s 443us/step - loss: 1.047
1 - acc: 0.5605 - val_loss: 1.2123 - val_acc: 0.4711
Epoch 66/80
10240/10240 [==============================] - 5s 455us/step - loss: 1.047
0 - acc: 0.5642 - val_loss: 1.1850 - val_acc: 0.4844
Epoch 67/80
10240/10240 [==============================] - 5s 482us/step - loss: 1.047
6 - acc: 0.5588 - val_loss: 1.1961 - val_acc: 0.4820
Epoch 68/80
10240/10240 [==============================] - 5s 457us/step - loss: 1.043
0 - acc: 0.5632 - val_loss: 1.1887 - val_acc: 0.4922
Epoch 69/80
10240/10240 [==============================] - 5s 452us/step - loss: 1.045
6 - acc: 0.5653 - val_loss: 1.1817 - val_acc: 0.4922
Epoch 70/80
10240/10240 [==============================] - 5s 452us/step - loss: 1.043
2 - acc: 0.5611 - val_loss: 1.1829 - val_acc: 0.4938
Epoch 71/80
10240/10240 [==============================] - 5s 470us/step - loss: 1.042
5 - acc: 0.5632 - val_loss: 1.1831 - val_acc: 0.4891
Epoch 72/80
10240/10240 [==============================] - 5s 452us/step - loss: 1.039
9 - acc: 0.5698 - val_loss: 1.1879 - val_acc: 0.4816
Epoch 73/80
10240/10240 [==============================] - 5s 451us/step - loss: 1.039
2 - acc: 0.5699 - val_loss: 1.1978 - val_acc: 0.4855
Epoch 74/80
10240/10240 [==============================] - 5s 474us/step - loss: 1.035
9 - acc: 0.5667 - val_loss: 1.2100 - val_acc: 0.4789
Epoch 75/80
10240/10240 [==============================] - 5s 452us/step - loss: 1.031
9 - acc: 0.5720 - val_loss: 1.1932 - val_acc: 0.4922
Epoch 76/80
10240/10240 [==============================] - 5s 456us/step - loss: 1.033
8 - acc: 0.5687 - val_loss: 1.2150 - val_acc: 0.4820
Epoch 77/80
10240/10240 [==============================] - 5s 452us/step - loss: 1.035
1 - acc: 0.5719 - val_loss: 1.1890 - val_acc: 0.4934
Epoch 78/80
10240/10240 [==============================] - 5s 479us/step - loss: 1.034
6 - acc: 0.5626 - val_loss: 1.2119 - val_acc: 0.4793
Epoch 79/80
10240/10240 [==============================] - 5s 452us/step - loss: 1.031
3 - acc: 0.5713 - val_loss: 1.2015 - val_acc: 0.4738
Epoch 80/80
10240/10240 [==============================] - 5s 452us/step - loss: 1.035
4 - acc: 0.5666 - val_loss: 1.2215 - val_acc: 0.4680
```

In [61]:

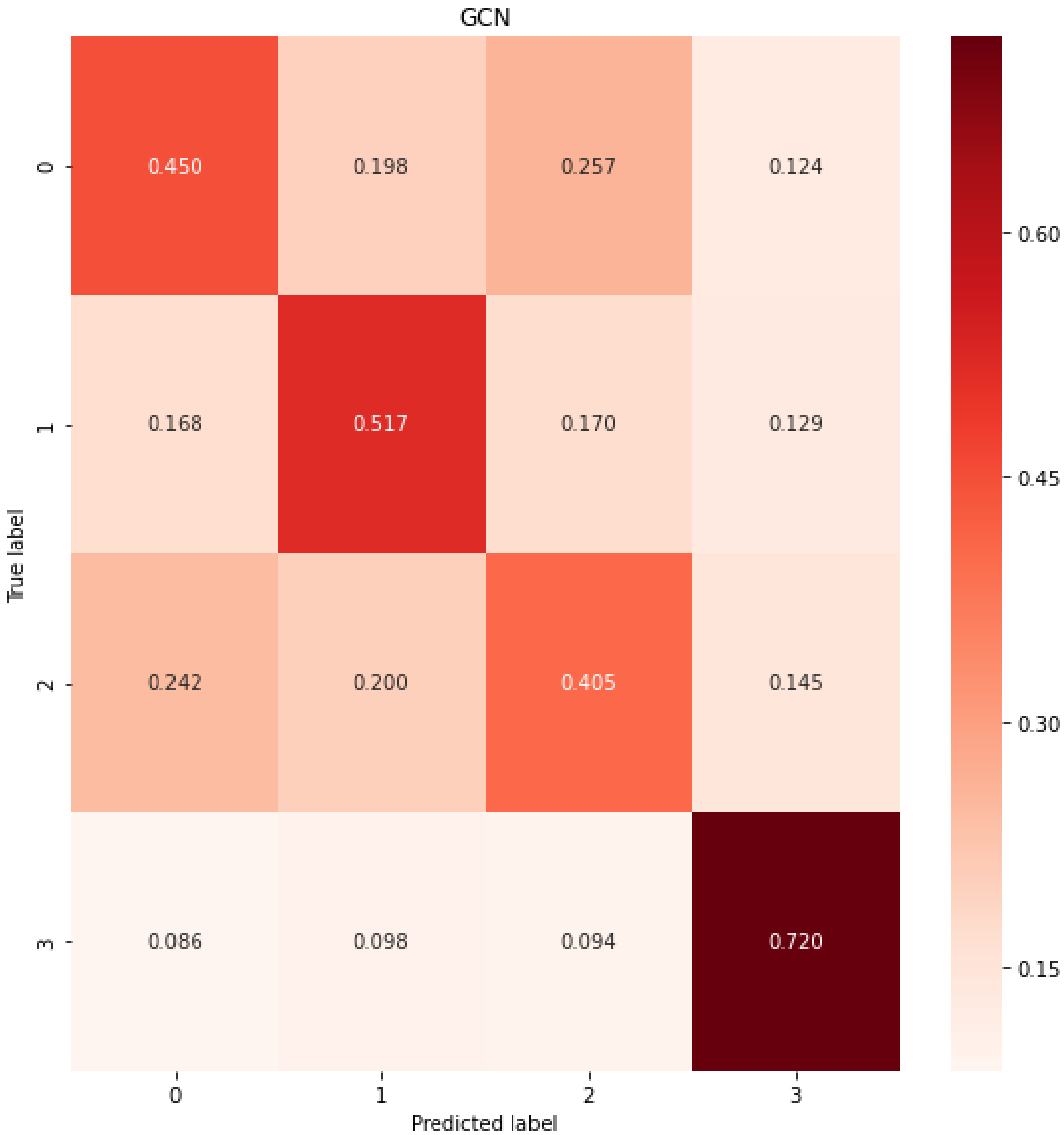
```
for emotion, model_i in d_emotion_models.items():
    eval_results = model_i.evaluate(X_test,
                                    y_test,
                                    batch_size=user_model_batch)
    print('Emotion %s' % train_labels[emotion])
    print('Test loss: {}\n'
          'Test acc: {}'.format(*eval_results))

    test_scores.append({
        'model': 'GCN trimmed ',
        'emotion': emotion,
        'accuracy': eval_results[1]
    })
```

```
2560/2560 [==============================] - 0s 148us/step
Emotion angry
Test loss: 1.1814735934138298
Test acc: 0.481640625
2560/2560 [==============================] - 0s 145us/step
Emotion happy
Test loss: 1.2232192665338517
Test acc: 0.4796875
2560/2560 [==============================] - 0s 141us/step
Emotion sad
Test loss: 1.2358716316521168
Test acc: 0.47421875
2560/2560 [==============================] - 0s 145us/step
Emotion surprise
Test loss: 1.2215377621352672
Test acc: 0.46796875
```

In [62]:

```
def plot_confusion_matrix(cm, classes=list(range(num_labels))):
    cm_df = pd.DataFrame(cm, index=classes, columns=classes)
    fig, ax = plt.subplots(figsize=(8, 8))
    ax = sns.heatmap(cm_df,
                     fmt='.3f',
                     annot=True, cmap='Reds', ax=ax)
    ax.set_ylabel('True label')
    ax.set_xlabel('Predicted label')
    fig.tight_layout()
    return fig
y_test_preds = model_full_grid.predict(X_test)
print(y_test_preds.shape)
cm = metrics.confusion_matrix(y_test, np.argmax(y_test_preds, axis=1))
fig = plot_confusion_matrix(cm/cm.sum(axis=1))
fig.get_axes()[0].set_title('GCN');
for i in range(0,num_labels):
    print("Emotion mapping  {} : {} ".format(i,train_labels[i]))
```

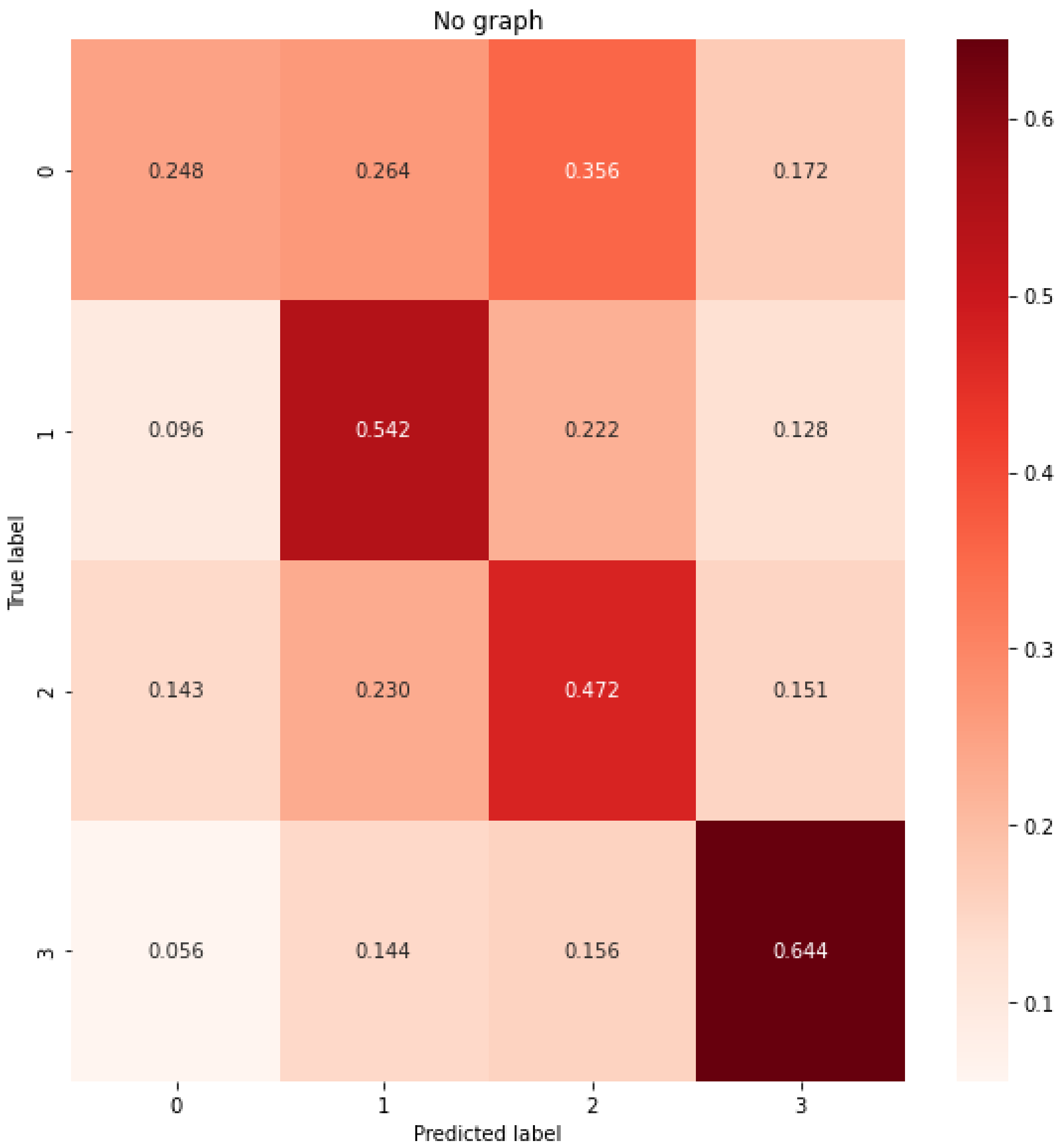
```
(2560, 10)
Emotion mapping  0 : angry
Emotion mapping  1 : happy
Emotion mapping  2 : sad
Emotion mapping  3 : surprise
```



In [63]:

```
y_test_preds = model_no_graph.predict(X_test)
print(y_test_preds.shape)
cm = metrics.confusion_matrix(y_test, np.argmax(y_test_preds, axis=1))
fig = plot_confusion_matrix(cm/cm.sum(axis=1))
fig.get_axes()[0].set_title('No graph');
for i in range(0,num_labels):
    print("Emotion mapping  {} : {} ".format(i,train_labels[i]))
```

```
(2560, 10)
Emotion mapping  0 : angry
Emotion mapping  1 : happy
Emotion mapping  2 : sad
Emotion mapping  3 : surprise
```



In [64]:

```
acc_df = {}
for model_name, model in d_emotion_models.items():

    y_test_preds = model.predict(X_test)
    cm = metrics.confusion_matrix(y_test, np.argmax(y_test_preds, axis=1))


    acc_per_classes = np.diag(cm/cm.sum(axis=1))


    acc_df[model_name] = acc_per_classes
```

Finding the distribution

In [65]:

```
d_emotion_corr_graphs = {}


for i in range(num_labels):
    mask = y_train == i

    dist = metrics.pairwise_distances(X_train[mask].reshape(-1, 784).T, metric='cosine'
, n_jobs=-2)

    W = sp.coo_matrix(1 - dist, dtype=np.float32)

    # No self-connections.
    W.setdiag(0)

    # Non-directed graph.
    bigger = W.T > W
    W = W - W.multiply(bigger) + W.T.multiply(bigger)

    assert W.nnz % 2 == 0
    assert np.abs(W - W.T).mean() < 1e-10
    assert type(W) is sp.csr.csr_matrix

    fig, axes = plt.subplots(figsize=(15, 5), ncols=3)

    x_train_i_avg = X_train[mask].mean(axis=0).flatten()
    axes[0].imshow(x_train_i_avg.reshape(28, 28))

    # thresholding
    W = W.multiply(W > 0.8)

    d_emotion_corr_graphs[i] = W

    axes[1] = create_graph(W, ax=axes[1], size_factor=1)

    axes[2] = create_graph(W, ax=axes[2], size_factor=1, spring_layout=True)
    fig.tight_layout()
    plt.show()
```

```
Number of nodes: 784; Number of edges: 250706
Number of nodes: 784; Number of edges: 250706
After removing nodes without edges:
Number of nodes: 784; Number of edges: 250706
```


```
Number of nodes: 784; Number of edges: 267144
Number of nodes: 784; Number of edges: 267144
After removing nodes without edges:
Number of nodes: 784; Number of edges: 267144
```

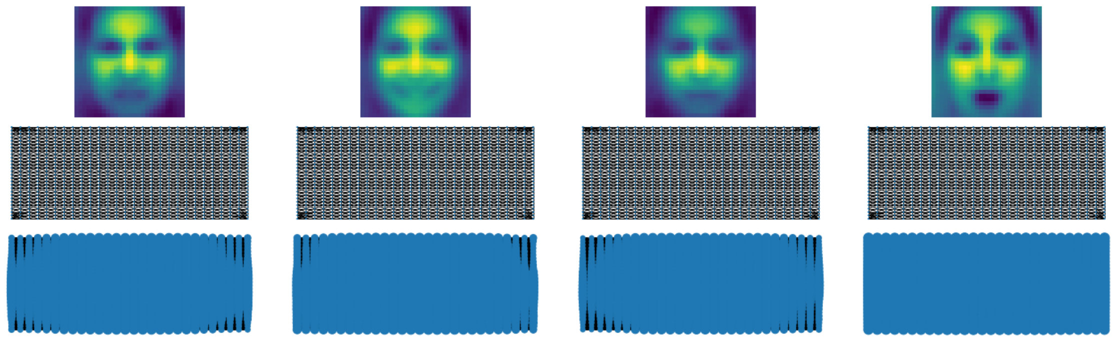

```
Number of nodes: 784; Number of edges: 242263
Number of nodes: 784; Number of edges: 242263
After removing nodes without edges:
Number of nodes: 784; Number of edges: 242263
```


```
Number of nodes: 784; Number of edges: 300470
Number of nodes: 784; Number of edges: 300470
After removing nodes without edges:
Number of nodes: 784; Number of edges: 300470
```

In [66]:

```
fig, axes = plt.subplots(figsize=(20, 6), nrows=3, ncols=num_labels)

for i in range(num_labels):
    mask = y_train == i
    x_train_i_avg = X_train[mask].mean(axis=0).flatten()
    axes[0, i].imshow(x_train_i_avg.reshape(28, 28))
    axes[0, i].axis('off')

    axes[1, i] = create_graph(d_emotion_graphs[i], ax=axes[1, i], size_factor=0.2)
    axes[2, i] = create_graph(d_emotion_corr_graphs[i], ax=axes[2, i], size_factor=0.2)


fig.tight_layout()
fig.subplots_adjust(wspace=0, hspace=0)
```

```
Number of nodes: 784; Number of edges: 3198
Number of nodes: 784; Number of edges: 250706
Number of nodes: 784; Number of edges: 3198
Number of nodes: 784; Number of edges: 267144
Number of nodes: 784; Number of edges: 3198
Number of nodes: 784; Number of edges: 242263
Number of nodes: 784; Number of edges: 3198
Number of nodes: 784; Number of edges: 300470
```



In [67]:

```
y_test_preds = model_full_grid.predict(X_test)
cm = metrics.confusion_matrix(y_test, np.argmax(y_test_preds, axis=1))
acc_per_class_full_model = np.diag(cm/cm.sum(axis=1))
acc_per_class_full_model
for i in range(0,num_labels):
    print("Emotion efficency : {} :{} ".format(train_labels[i],acc_per_class_full_model
[i]))
```

```
Emotion efficency : angry :0.4496240601503759
Emotion efficency : happy :0.5168
Emotion efficency : sad :0.4047244094488189
Emotion efficency : surprise :0.7196850393700788
```

In [ ]:

```
```