Node Classification using Graph Convolutional Networks

This node classification task uses CORA dataset from https://linqs.soe.ucsc.edu/data
The dataset consists of **2708** nodes which correspond to scientific publications.
The nodes are classified into **7** categories indicating the topics of each document.
The edges indicate whether a document is cited by the other or vice versa.
Each node has **1433** features which is described by a 0/1-valued vector, indicating the bag-of-words from the dictionary.

This is an undirected graph problem

In [ ]:
```
#importing dependencies

import numpy as np
import os
import networkx as nx
from keras.utils import to_categorical
from sklearn.preprocessing import LabelEncoder
from sklearn.utils import shuffle
from sklearn.metrics import classification_report

from spektral.layers import GraphConv

from tensorflow.keras.models import Model
from tensorflow.keras.layers import Input, Dropout, Dense
from tensorflow.keras import Sequential
from tensorflow.keras.optimizers import Adam
from tensorflow.keras.callbacks import TensorBoard, EarlyStopping
import tensorflow as tf
from tensorflow.keras.regularizers import l2

from collections import Counter
from sklearn.manifold import TSNE
import matplotlib.pyplot as plt
```

Data Loading and Preprocessing

We are going to use the edges connecting the (from file **cora.cites**).
The nodes are loaded from file **cora.content**.

In [ ]:
```
#Loading the data

all_data = []
all_edges = []

for root,dirs,files in os.walk('./cora'):
    for file in files:
        if '.content' in file:
            with open(os.path.join(root,file),'r') as f:
                all_data.extend(f.read().splitlines())
        elif 'cites' in file:
            with open(os.path.join(root,file),'r') as f:
                all_edges.extend(f.read().splitlines())


#Shuffle the data because the raw data is ordered based on the label
random_state = 77
all_data = shuffle(all_data,random_state=random_state)
```

In **cora.content** file:
The **first** element indicates the **node name**

The **second** until the last second elements indicate the **node features**
The **last** element indicates the **label of that particular node**

In **cora.cites** file:
Each line indicates the tuple of connected nodes

Parsing the data

In [ ]:
```
#parse the data
labels = []
nodes = []
X = []

for i,data in enumerate(all_data):
    elements = data.split('\t')
    labels.append(elements[-1])
    X.append(elements[1:-1])
    nodes.append(elements[0])

X = np.array(X,dtype=int)
N = X.shape[0] #the number of nodes
F = X.shape[1] #the size of node features
print('X shape: ', X.shape)


#parse the edge
edge_list=[]
for edge in all_edges:
    e = edge.split('\t')
    edge_list.append((e[0],e[1]))

print('\nNumber of nodes (N): ', N)
print('\nNumber of features (F) of each node: ', F)
print('\nCategories: ', set(labels))

num_classes = len(set(labels))
print('\nNumber of classes: ', num_classes)
```

```
X shape:  (2708, 1433)

Number of nodes (N):  2708

Number of features (F) of each node:  1433

Categories:  {'Probabilistic_Methods', 'Theory', 'Neural_Networks', 'Reinforcement_Learning', 'Case_Based',
'Rule_Learning', 'Genetic_Algorithms'}

Number of classes:  7
```

Select examples for training, validation, and test then set the mask

In [ ]:
```
def limit_data(labels,limit=20,val_num=500,test_num=1000):
    '''
    Get the index of train, validation, and test data
    '''
    label_counter = dict((l, 0) for l in labels)
    train_idx = []

    for i in range(len(labels)):
        label = labels[i]
        if label_counter[label]<limit:
            #add the example to the training data
            train_idx.append(i)
            label_counter[label]+=1

        #exit the loop once we found 20 examples for each class
        if all(count == limit for count in label_counter.values()):
            break
```

```
    #get the indices that do not go to traning data
    rest_idx = [x for x in range(len(labels)) if x not in train_idx]
    #get the first val_num
    val_idx = rest_idx[:val_num]
    test_idx = rest_idx[val_num:(val_num+test_num)]
    return train_idx, val_idx,test_idx


train_idx,val_idx,test_idx = limit_data(labels)
```

In [ ]:
```
#set the mask
train_mask = np.zeros((N,),dtype=bool)
train_mask[train_idx] = True

val_mask = np.zeros((N,),dtype=bool)
val_mask[val_idx] = True

test_mask = np.zeros((N,),dtype=bool)
test_mask[test_idx] = True
```

Show Data Distribution

In [ ]:
```
print("All Data Distribution: \n{}".format(Counter(labels)))
```

```
All Data Distribution: 
Counter({'Neural_Networks': 818, 'Probabilistic_Methods': 426, 'Genetic_Algorithms': 418, 'Theory': 351, 'Cas
e_Based': 298, 'Reinforcement_Learning': 217, 'Rule_Learning': 180})
```

In [ ]:
```
print("Training Data Distribution: \n{}".format(Counter([labels[i] for i in train_idx])))
```

```
Training Data Distribution: 
Counter({'Reinforcement_Learning': 20, 'Probabilistic_Methods': 20, 'Neural_Networks': 20, 'Case_Based': 20,
'Theory': 20, 'Genetic_Algorithms': 20, 'Rule_Learning': 20})
```

In [ ]:
```
print("Validation Data Distribution: \n{}".format(Counter([labels[i] for i in val_idx])))
```

```
Validation Data Distribution: 
Counter({'Neural_Networks': 172, 'Genetic_Algorithms': 78, 'Probabilistic_Methods': 72, 'Theory': 63, 'Case_B
ased': 58, 'Reinforcement_Learning': 35, 'Rule_Learning': 22})
```

Convert the labels to one hot encoding

In [ ]:
```
def encode_label(labels):
    label_encoder = LabelEncoder()
    labels = label_encoder.fit_transform(labels)
    labels = to_categorical(labels)
    return labels, label_encoder.classes_

labels_encoded, classes = encode_label(labels)
```

Build a graph on NetworkX using the obtained nodes and edges list

In [ ]:
```
#build the graph
G = nx.Graph()
G.add_nodes_from(nodes)
G.add_edges_from(edge_list)

#obtain the adjacency matrix (A)
A = nx.adjacency_matrix(G)
print('Graph info: ', nx.info(G))
```

```
Graph info:  Name: 
Type: Graph
Number of nodes: 2708
Number of edges: 5278
Average degree:   3.8981
```

Building and Training Graph Convolutional Networks

In [ ]:
```
# Parameters
channels = 16           # Number of channels in the first layer
dropout = 0.5           # Dropout rate for the features
l2_reg = 5e-4           # L2 regularization rate
learning_rate = 1e-2    # Learning rate
epochs = 200            # Number of training epochs
es_patience = 100        # Patience for early stopping

# Preprocessing operations
A = GraphConv.preprocess(A).astype('f4')

# Model definition
X_in = Input(shape=(F, ))
fltr_in = Input((N, ), sparse=True)

dropout_1 = Dropout(dropout)(X_in)
graph_conv_1 = GraphConv(channels,
                         activation='relu',
                         kernel_regularizer=l2(l2_reg),
                         use_bias=False)([dropout_1, fltr_in])

dropout_2 = Dropout(dropout)(graph_conv_1)
graph_conv_2 = GraphConv(num_classes,
                         activation='softmax',
                         use_bias=False)([dropout_2, fltr_in])

# Build model
model = Model(inputs=[X_in, fltr_in], outputs=graph_conv_2)
optimizer = Adam(lr=learning_rate)
model.compile(optimizer=optimizer,
              loss='categorical_crossentropy',
              weighted_metrics=['acc'])
model.summary()

tbCallBack_GCN = tf.keras.callbacks.TensorBoard(
    log_dir='./Tensorboard_GCN_cora',
)
callback_GCN = [tbCallBack_GCN]
```

```
Model: "model"
__________________________________________________________________________________________________
Layer (type)                    Output Shape         Param #     Connected to
==================================================================================================
input_1 (InputLayer)            [(None, 1433)]       0
__________________________________________________________________________________________________
dropout (Dropout)               (None, 1433)         0           input_1[0][0]
__________________________________________________________________________________________________
input_2 (InputLayer)            [(None, 2708)]       0
__________________________________________________________________________________________________
graph_conv (GraphConv)          (None, 16)           22928       dropout[0][0]
                                                                 input_2[0][0]
__________________________________________________________________________________________________
dropout_1 (Dropout)             (None, 16)           0           graph_conv[0][0]
__________________________________________________________________________________________________
graph_conv_1 (GraphConv)        (None, 7)            112         dropout_1[0][0]
                                                                 input_2[0][0]
==================================================================================================
Total params: 23,040
Trainable params: 23,040
Non-trainable params: 0
__________________________________________________________________________________________________
```

In [ ]:
```
# Train model
validation_data = ([X, A], labels_encoded, val_mask)
model.fit([X, A],
          labels_encoded,
          sample_weight=train_mask,
          epochs=epochs,
```

```
          batch_size=N,
          validation_data=validation_data,
          shuffle=False,
          callbacks=[
              EarlyStopping(patience=es_patience,  restore_best_weights=True),
              tbCallBack_GCN
          ])
```

```
Epoch 1/200
1/1 [==============================] - 0s 470ms/step - loss: 0.1162 - acc: 0.1143 - val_loss: 0.3629 - val_ac
c: 0.4000
Epoch 2/200
1/1 [==============================] - ETA: 0s - loss: 0.1088 - acc: 0.3643WARNING:tensorflow:Method (on_trai
n_batch_end) is slow compared to the batch update (0.205158). Check your callbacks.
1/1 [==============================] - 0s 204ms/step - loss: 0.1088 - acc: 0.3643 - val_loss: 0.3503 - val_ac
c: 0.5460
Epoch 3/200
1/1 [==============================] - 0s 246ms/step - loss: 0.1018 - acc: 0.5929 - val_loss: 0.3373 - val_ac
c: 0.6360
Epoch 4/200
1/1 [==============================] - 0s 320ms/step - loss: 0.0954 - acc: 0.7000 - val_loss: 0.3264 - val_ac
c: 0.6620
Epoch 5/200
1/1 [==============================] - 0s 351ms/step - loss: 0.0896 - acc: 0.7286 - val_loss: 0.3175 - val_ac
c: 0.6740
Epoch 6/200
1/1 [==============================] - 0s 278ms/step - loss: 0.0836 - acc: 0.8214 - val_loss: 0.3088 - val_ac
c: 0.6720
Epoch 7/200
1/1 [==============================] - 0s 305ms/step - loss: 0.0812 - acc: 0.7857 - val_loss: 0.3005 - val_ac
c: 0.6860
Epoch 8/200
1/1 [==============================] - 0s 277ms/step - loss: 0.0788 - acc: 0.8571 - val_loss: 0.2926 - val_ac
c: 0.7000
Epoch 9/200
1/1 [==============================] - 0s 273ms/step - loss: 0.0756 - acc: 0.7786 - val_loss: 0.2841 - val_ac
c: 0.7080
Epoch 10/200
1/1 [==============================] - 0s 296ms/step - loss: 0.0705 - acc: 0.8500 - val_loss: 0.2757 - val_ac
c: 0.7260
Epoch 11/200
1/1 [==============================] - 0s 282ms/step - loss: 0.0689 - acc: 0.9000 - val_loss: 0.2674 - val_ac
c: 0.7300
Epoch 12/200
1/1 [==============================] - 0s 328ms/step - loss: 0.0662 - acc: 0.9143 - val_loss: 0.2595 - val_ac
c: 0.7320
Epoch 13/200
1/1 [==============================] - 0s 303ms/step - loss: 0.0663 - acc: 0.8929 - val_loss: 0.2524 - val_ac
c: 0.7420
Epoch 14/200
1/1 [==============================] - 0s 331ms/step - loss: 0.0618 - acc: 0.9357 - val_loss: 0.2461 - val_ac
c: 0.7460
Epoch 15/200
1/1 [==============================] - 0s 294ms/step - loss: 0.0627 - acc: 0.9143 - val_loss: 0.2400 - val_ac
c: 0.7500
Epoch 16/200
1/1 [==============================] - 0s 307ms/step - loss: 0.0619 - acc: 0.8643 - val_loss: 0.2350 - val_ac
c: 0.7600
Epoch 17/200
1/1 [==============================] - 0s 278ms/step - loss: 0.0598 - acc: 0.9286 - val_loss: 0.2306 - val_ac
c: 0.7640
Epoch 18/200
1/1 [==============================] - 0s 286ms/step - loss: 0.0631 - acc: 0.8429 - val_loss: 0.2271 - val_ac
c: 0.7620
Epoch 19/200
1/1 [==============================] - 0s 402ms/step - loss: 0.0570 - acc: 0.9214 - val_loss: 0.2239 - val_ac
c: 0.7640
Epoch 20/200
1/1 [==============================] - 0s 417ms/step - loss: 0.0592 - acc: 0.9000 - val_loss: 0.2210 - val_ac
c: 0.7600
Epoch 21/200
1/1 [==============================] - 0s 340ms/step - loss: 0.0565 - acc: 0.8929 - val_loss: 0.2181 - val_ac
c: 0.7600
Epoch 22/200
1/1 [==============================] - 0s 268ms/step - loss: 0.0547 - acc: 0.9143 - val_loss: 0.2148 - val_ac
c: 0.7600
Epoch 23/200
1/1 [==============================] - 0s 256ms/step - loss: 0.0529 - acc: 0.9286 - val_loss: 0.2117 - val_ac
c: 0.7620
```

```
Epoch 24/200
1/1 [==============================] - 0s 290ms/step - loss: 0.0534 - acc: 0.9071 - val_loss: 0.2085 - val_ac
c: 0.7640
Epoch 25/200
1/1 [==============================] - 0s 279ms/step - loss: 0.0519 - acc: 0.9429 - val_loss: 0.2054 - val_ac
c: 0.7620
Epoch 26/200
1/1 [==============================] - 0s 228ms/step - loss: 0.0484 - acc: 0.9500 - val_loss: 0.2028 - val_ac
c: 0.7720
Epoch 27/200
1/1 [==============================] - 0s 231ms/step - loss: 0.0485 - acc: 0.9357 - val_loss: 0.2001 - val_ac
c: 0.7740
Epoch 28/200
1/1 [==============================] - 0s 248ms/step - loss: 0.0490 - acc: 0.9500 - val_loss: 0.1975 - val_ac
c: 0.7740
Epoch 29/200
1/1 [==============================] - 0s 245ms/step - loss: 0.0478 - acc: 0.9429 - val_loss: 0.1951 - val_ac
c: 0.7660
Epoch 30/200
1/1 [==============================] - 0s 239ms/step - loss: 0.0505 - acc: 0.9357 - val_loss: 0.1928 - val_ac
c: 0.7600
Epoch 31/200
1/1 [==============================] - 0s 190ms/step - loss: 0.0491 - acc: 0.9143 - val_loss: 0.1909 - val_ac
c: 0.7620
Epoch 32/200
1/1 [==============================] - 0s 192ms/step - loss: 0.0471 - acc: 0.9357 - val_loss: 0.1895 - val_ac
c: 0.7620
Epoch 33/200
1/1 [==============================] - 0s 185ms/step - loss: 0.0470 - acc: 0.9429 - val_loss: 0.1885 - val_ac
c: 0.7620
Epoch 34/200
1/1 [==============================] - 0s 185ms/step - loss: 0.0438 - acc: 0.9643 - val_loss: 0.1873 - val_ac
c: 0.7640
Epoch 35/200
1/1 [==============================] - 0s 194ms/step - loss: 0.0460 - acc: 0.9214 - val_loss: 0.1858 - val_ac
c: 0.7680
Epoch 36/200
1/1 [==============================] - 0s 286ms/step - loss: 0.0463 - acc: 0.9429 - val_loss: 0.1842 - val_ac
c: 0.7780
Epoch 37/200
1/1 [==============================] - 0s 260ms/step - loss: 0.0440 - acc: 0.9429 - val_loss: 0.1828 - val_ac
c: 0.7800
Epoch 38/200
1/1 [==============================] - 0s 215ms/step - loss: 0.0442 - acc: 0.9571 - val_loss: 0.1813 - val_ac
c: 0.7900
Epoch 39/200
1/1 [==============================] - 0s 406ms/step - loss: 0.0441 - acc: 0.9286 - val_loss: 0.1805 - val_ac
c: 0.7880
Epoch 40/200
1/1 [==============================] - 0s 210ms/step - loss: 0.0408 - acc: 0.9714 - val_loss: 0.1798 - val_ac
c: 0.7820
Epoch 41/200
1/1 [==============================] - 0s 187ms/step - loss: 0.0427 - acc: 0.9429 - val_loss: 0.1787 - val_ac
c: 0.7760
Epoch 42/200
1/1 [==============================] - 0s 185ms/step - loss: 0.0435 - acc: 0.9357 - val_loss: 0.1778 - val_ac
c: 0.7780
Epoch 43/200
1/1 [==============================] - 0s 206ms/step - loss: 0.0419 - acc: 0.9429 - val_loss: 0.1774 - val_ac
c: 0.7740
Epoch 44/200
1/1 [==============================] - 0s 302ms/step - loss: 0.0413 - acc: 0.9500 - val_loss: 0.1770 - val_ac
c: 0.7680
Epoch 45/200
1/1 [==============================] - 0s 213ms/step - loss: 0.0419 - acc: 0.9143 - val_loss: 0.1766 - val_ac
c: 0.7740
Epoch 46/200
1/1 [==============================] - 0s 213ms/step - loss: 0.0417 - acc: 0.9643 - val_loss: 0.1755 - val_ac
c: 0.7700
Epoch 47/200
1/1 [==============================] - 0s 200ms/step - loss: 0.0414 - acc: 0.9214 - val_loss: 0.1731 - val_ac
```

```
c: 0.7700
Epoch 48/200
1/1 [==============================] - 0s 188ms/step - loss: 0.0410 - acc: 0.9643 - val_loss: 0.1703 - val_ac
c: 0.7880
Epoch 49/200
1/1 [==============================] - 0s 201ms/step - loss: 0.0386 - acc: 0.9786 - val_loss: 0.1679 - val_ac
c: 0.7860
Epoch 50/200
1/1 [==============================] - 0s 208ms/step - loss: 0.0415 - acc: 0.9500 - val_loss: 0.1663 - val_ac
c: 0.7900
Epoch 51/200
1/1 [==============================] - 0s 203ms/step - loss: 0.0393 - acc: 0.9643 - val_loss: 0.1655 - val_ac
c: 0.7880
Epoch 52/200
1/1 [==============================] - 0s 193ms/step - loss: 0.0402 - acc: 0.9500 - val_loss: 0.1659 - val_ac
c: 0.7840
Epoch 53/200
1/1 [==============================] - 0s 217ms/step - loss: 0.0381 - acc: 0.9714 - val_loss: 0.1676 - val_ac
c: 0.7780
Epoch 54/200
1/1 [==============================] - 0s 216ms/step - loss: 0.0394 - acc: 0.9286 - val_loss: 0.1692 - val_ac
c: 0.7720
Epoch 55/200
1/1 [==============================] - 0s 207ms/step - loss: 0.0377 - acc: 0.9571 - val_loss: 0.1712 - val_ac
c: 0.7680
Epoch 56/200
1/1 [==============================] - 0s 224ms/step - loss: 0.0395 - acc: 0.9571 - val_loss: 0.1717 - val_ac
c: 0.7680
Epoch 57/200
1/1 [==============================] - 0s 211ms/step - loss: 0.0362 - acc: 0.9571 - val_loss: 0.1708 - val_ac
c: 0.7720
Epoch 58/200
1/1 [==============================] - 0s 192ms/step - loss: 0.0378 - acc: 0.9357 - val_loss: 0.1690 - val_ac
c: 0.7880
Epoch 59/200
1/1 [==============================] - 0s 197ms/step - loss: 0.0359 - acc: 0.9571 - val_loss: 0.1674 - val_ac
c: 0.7840
Epoch 60/200
1/1 [==============================] - 0s 196ms/step - loss: 0.0373 - acc: 0.9786 - val_loss: 0.1658 - val_ac
c: 0.7840
Epoch 61/200
1/1 [==============================] - 0s 192ms/step - loss: 0.0387 - acc: 0.9357 - val_loss: 0.1637 - val_ac
c: 0.7900
Epoch 62/200
1/1 [==============================] - 0s 184ms/step - loss: 0.0375 - acc: 0.9500 - val_loss: 0.1623 - val_ac
c: 0.7800
Epoch 63/200
1/1 [==============================] - 0s 194ms/step - loss: 0.0347 - acc: 0.9643 - val_loss: 0.1615 - val_ac
c: 0.7780
Epoch 64/200
1/1 [==============================] - 0s 185ms/step - loss: 0.0363 - acc: 0.9500 - val_loss: 0.1615 - val_ac
c: 0.7700
Epoch 65/200
1/1 [==============================] - 0s 197ms/step - loss: 0.0362 - acc: 0.9500 - val_loss: 0.1620 - val_ac
c: 0.7700
Epoch 66/200
1/1 [==============================] - 0s 180ms/step - loss: 0.0380 - acc: 0.9286 - val_loss: 0.1627 - val_ac
c: 0.7640
Epoch 67/200
1/1 [==============================] - 0s 184ms/step - loss: 0.0362 - acc: 0.9357 - val_loss: 0.1637 - val_ac
c: 0.7640
Epoch 68/200
1/1 [==============================] - 0s 200ms/step - loss: 0.0356 - acc: 0.9500 - val_loss: 0.1636 - val_ac
c: 0.7640
Epoch 69/200
1/1 [==============================] - 0s 203ms/step - loss: 0.0345 - acc: 0.9500 - val_loss: 0.1629 - val_ac
c: 0.7700
Epoch 70/200
1/1 [==============================] - 0s 193ms/step - loss: 0.0347 - acc: 0.9429 - val_loss: 0.1613 - val_ac
c: 0.7780
Epoch 71/200
```

```
1/1 [==============================] - 0s 193ms/step - loss: 0.0321 - acc: 0.9571 - val_loss: 0.1605 - val_ac
c: 0.7820
Epoch 72/200
1/1 [==============================] - 0s 191ms/step - loss: 0.0335 - acc: 0.9857 - val_loss: 0.1598 - val_ac
c: 0.7820
Epoch 73/200
1/1 [==============================] - 0s 186ms/step - loss: 0.0345 - acc: 0.9643 - val_loss: 0.1584 - val_ac
c: 0.7840
Epoch 74/200
1/1 [==============================] - 0s 189ms/step - loss: 0.0324 - acc: 0.9643 - val_loss: 0.1576 - val_ac
c: 0.7780
Epoch 75/200
1/1 [==============================] - 0s 188ms/step - loss: 0.0344 - acc: 0.9643 - val_loss: 0.1578 - val_ac
c: 0.7700
Epoch 76/200
1/1 [==============================] - 0s 207ms/step - loss: 0.0322 - acc: 0.9714 - val_loss: 0.1586 - val_ac
c: 0.7620
Epoch 77/200
1/1 [==============================] - 0s 197ms/step - loss: 0.0329 - acc: 0.9571 - val_loss: 0.1599 - val_ac
c: 0.7600
Epoch 78/200
1/1 [==============================] - 0s 218ms/step - loss: 0.0339 - acc: 0.9643 - val_loss: 0.1615 - val_ac
c: 0.7580
Epoch 79/200
1/1 [==============================] - 0s 184ms/step - loss: 0.0334 - acc: 0.9571 - val_loss: 0.1639 - val_ac
c: 0.7540
Epoch 80/200
1/1 [==============================] - 0s 193ms/step - loss: 0.0359 - acc: 0.9643 - val_loss: 0.1655 - val_ac
c: 0.7480
Epoch 81/200
1/1 [==============================] - 0s 198ms/step - loss: 0.0331 - acc: 0.9500 - val_loss: 0.1647 - val_ac
c: 0.7560
Epoch 82/200
1/1 [==============================] - 0s 189ms/step - loss: 0.0341 - acc: 0.9500 - val_loss: 0.1626 - val_ac
c: 0.7720
Epoch 83/200
1/1 [==============================] - 0s 186ms/step - loss: 0.0329 - acc: 0.9643 - val_loss: 0.1594 - val_ac
c: 0.7820
Epoch 84/200
1/1 [==============================] - 0s 185ms/step - loss: 0.0300 - acc: 0.9857 - val_loss: 0.1570 - val_ac
c: 0.7780
Epoch 85/200
1/1 [==============================] - 0s 188ms/step - loss: 0.0317 - acc: 0.9643 - val_loss: 0.1547 - val_ac
c: 0.7820
Epoch 86/200
1/1 [==============================] - 0s 191ms/step - loss: 0.0328 - acc: 0.9500 - val_loss: 0.1539 - val_ac
c: 0.7820
Epoch 87/200
1/1 [==============================] - 0s 183ms/step - loss: 0.0322 - acc: 0.9500 - val_loss: 0.1546 - val_ac
c: 0.7720
Epoch 88/200
1/1 [==============================] - 0s 183ms/step - loss: 0.0306 - acc: 0.9857 - val_loss: 0.1556 - val_ac
c: 0.7740
Epoch 89/200
1/1 [==============================] - 0s 184ms/step - loss: 0.0316 - acc: 0.9714 - val_loss: 0.1561 - val_ac
c: 0.7720
Epoch 90/200
1/1 [==============================] - 0s 186ms/step - loss: 0.0312 - acc: 0.9571 - val_loss: 0.1550 - val_ac
c: 0.7740
Epoch 91/200
1/1 [==============================] - 0s 187ms/step - loss: 0.0296 - acc: 0.9857 - val_loss: 0.1537 - val_ac
c: 0.7740
Epoch 92/200
1/1 [==============================] - 0s 189ms/step - loss: 0.0270 - acc: 0.9929 - val_loss: 0.1524 - val_ac
c: 0.7760
Epoch 93/200
1/1 [==============================] - 0s 186ms/step - loss: 0.0299 - acc: 0.9786 - val_loss: 0.1507 - val_ac
c: 0.7780
Epoch 94/200
1/1 [==============================] - 0s 187ms/step - loss: 0.0297 - acc: 0.9500 - val_loss: 0.1501 - val_ac
c: 0.7780
```

```
Epoch 95/200
1/1 [==============================] - 0s 193ms/step - loss: 0.0305 - acc: 0.9571 - val_loss: 0.1494 - val_ac
c: 0.7780
Epoch 96/200
1/1 [==============================] - 0s 181ms/step - loss: 0.0309 - acc: 0.9429 - val_loss: 0.1496 - val_ac
c: 0.7820
Epoch 97/200
1/1 [==============================] - 0s 196ms/step - loss: 0.0291 - acc: 0.9857 - val_loss: 0.1513 - val_ac
c: 0.7800
Epoch 98/200
1/1 [==============================] - 0s 182ms/step - loss: 0.0317 - acc: 0.9643 - val_loss: 0.1525 - val_ac
c: 0.7780
Epoch 99/200
1/1 [==============================] - 0s 189ms/step - loss: 0.0292 - acc: 0.9500 - val_loss: 0.1520 - val_ac
c: 0.7820
Epoch 100/200
1/1 [==============================] - 0s 192ms/step - loss: 0.0289 - acc: 0.9714 - val_loss: 0.1515 - val_ac
c: 0.7780
Epoch 101/200
1/1 [==============================] - 0s 188ms/step - loss: 0.0312 - acc: 0.9643 - val_loss: 0.1515 - val_ac
c: 0.7760
Epoch 102/200
1/1 [==============================] - 0s 189ms/step - loss: 0.0282 - acc: 0.9857 - val_loss: 0.1507 - val_ac
c: 0.7800
Epoch 103/200
1/1 [==============================] - 0s 210ms/step - loss: 0.0279 - acc: 0.9643 - val_loss: 0.1505 - val_ac
c: 0.7840
Epoch 104/200
1/1 [==============================] - 0s 192ms/step - loss: 0.0287 - acc: 0.9714 - val_loss: 0.1510 - val_ac
c: 0.7840
Epoch 105/200
1/1 [==============================] - 0s 188ms/step - loss: 0.0294 - acc: 0.9643 - val_loss: 0.1499 - val_ac
c: 0.7820
Epoch 106/200
1/1 [==============================] - 0s 185ms/step - loss: 0.0295 - acc: 0.9571 - val_loss: 0.1486 - val_ac
c: 0.7800
Epoch 107/200
1/1 [==============================] - 0s 192ms/step - loss: 0.0275 - acc: 0.9786 - val_loss: 0.1473 - val_ac
c: 0.7840
Epoch 108/200
1/1 [==============================] - 0s 188ms/step - loss: 0.0292 - acc: 0.9571 - val_loss: 0.1460 - val_ac
c: 0.7820
Epoch 109/200
1/1 [==============================] - 0s 189ms/step - loss: 0.0274 - acc: 1.0000 - val_loss: 0.1457 - val_ac
c: 0.7880
Epoch 110/200
1/1 [==============================] - 0s 191ms/step - loss: 0.0279 - acc: 0.9643 - val_loss: 0.1469 - val_ac
c: 0.7880
Epoch 111/200
1/1 [==============================] - 0s 191ms/step - loss: 0.0259 - acc: 0.9929 - val_loss: 0.1483 - val_ac
c: 0.7860
Epoch 112/200
1/1 [==============================] - 0s 199ms/step - loss: 0.0260 - acc: 0.9929 - val_loss: 0.1496 - val_ac
c: 0.7820
Epoch 113/200
1/1 [==============================] - 0s 195ms/step - loss: 0.0273 - acc: 0.9857 - val_loss: 0.1503 - val_ac
c: 0.7780
Epoch 114/200
1/1 [==============================] - 0s 188ms/step - loss: 0.0267 - acc: 0.9786 - val_loss: 0.1509 - val_ac
c: 0.7820
Epoch 115/200
1/1 [==============================] - 0s 182ms/step - loss: 0.0281 - acc: 0.9643 - val_loss: 0.1501 - val_ac
c: 0.7800
Epoch 116/200
1/1 [==============================] - 0s 183ms/step - loss: 0.0286 - acc: 0.9500 - val_loss: 0.1479 - val_ac
c: 0.7820
Epoch 117/200
1/1 [==============================] - 0s 188ms/step - loss: 0.0292 - acc: 0.9643 - val_loss: 0.1468 - val_ac
c: 0.7780
Epoch 118/200
1/1 [==============================] - 0s 187ms/step - loss: 0.0262 - acc: 0.9714 - val_loss: 0.1456 - val_ac
```

```
c: 0.7860
Epoch 119/200
1/1 [==============================] - 0s 182ms/step - loss: 0.0293 - acc: 0.9643 - val_loss: 0.1453 - val_ac
c: 0.7820
Epoch 120/200
1/1 [==============================] - 0s 194ms/step - loss: 0.0277 - acc: 0.9429 - val_loss: 0.1462 - val_ac
c: 0.7820
Epoch 121/200
1/1 [==============================] - 0s 203ms/step - loss: 0.0282 - acc: 0.9857 - val_loss: 0.1476 - val_ac
c: 0.7820
Epoch 122/200
1/1 [==============================] - 0s 224ms/step - loss: 0.0282 - acc: 0.9714 - val_loss: 0.1492 - val_ac
c: 0.7840
Epoch 123/200
1/1 [==============================] - 0s 204ms/step - loss: 0.0269 - acc: 1.0000 - val_loss: 0.1516 - val_ac
c: 0.7780
Epoch 124/200
1/1 [==============================] - 0s 194ms/step - loss: 0.0260 - acc: 0.9714 - val_loss: 0.1535 - val_ac
c: 0.7740
Epoch 125/200
1/1 [==============================] - 0s 224ms/step - loss: 0.0276 - acc: 0.9571 - val_loss: 0.1539 - val_ac
c: 0.7760
Epoch 126/200
1/1 [==============================] - 0s 233ms/step - loss: 0.0279 - acc: 0.9714 - val_loss: 0.1530 - val_ac
c: 0.7800
Epoch 127/200
1/1 [==============================] - 0s 187ms/step - loss: 0.0257 - acc: 0.9786 - val_loss: 0.1504 - val_ac
c: 0.7860
Epoch 128/200
1/1 [==============================] - 0s 231ms/step - loss: 0.0253 - acc: 0.9714 - val_loss: 0.1486 - val_ac
c: 0.7800
Epoch 129/200
1/1 [==============================] - 0s 260ms/step - loss: 0.0263 - acc: 0.9643 - val_loss: 0.1474 - val_ac
c: 0.7780
Epoch 130/200
1/1 [==============================] - 0s 182ms/step - loss: 0.0287 - acc: 0.9643 - val_loss: 0.1469 - val_ac
c: 0.7800
Epoch 131/200
1/1 [==============================] - 0s 217ms/step - loss: 0.0270 - acc: 0.9643 - val_loss: 0.1465 - val_ac
c: 0.7780
Epoch 132/200
1/1 [==============================] - 0s 302ms/step - loss: 0.0262 - acc: 0.9643 - val_loss: 0.1453 - val_ac
c: 0.7740
Epoch 133/200
1/1 [==============================] - 0s 203ms/step - loss: 0.0270 - acc: 0.9429 - val_loss: 0.1460 - val_ac
c: 0.7760
Epoch 134/200
1/1 [==============================] - 0s 195ms/step - loss: 0.0251 - acc: 0.9786 - val_loss: 0.1467 - val_ac
c: 0.7700
Epoch 135/200
1/1 [==============================] - 0s 252ms/step - loss: 0.0266 - acc: 0.9714 - val_loss: 0.1470 - val_ac
c: 0.7720
Epoch 136/200
1/1 [==============================] - 0s 191ms/step - loss: 0.0259 - acc: 0.9857 - val_loss: 0.1474 - val_ac
c: 0.7760
Epoch 137/200
1/1 [==============================] - 0s 218ms/step - loss: 0.0275 - acc: 0.9571 - val_loss: 0.1472 - val_ac
c: 0.7740
Epoch 138/200
1/1 [==============================] - 0s 195ms/step - loss: 0.0255 - acc: 0.9714 - val_loss: 0.1466 - val_ac
c: 0.7680
Epoch 139/200
1/1 [==============================] - 0s 192ms/step - loss: 0.0260 - acc: 0.9786 - val_loss: 0.1464 - val_ac
c: 0.7700
Epoch 140/200
1/1 [==============================] - 0s 188ms/step - loss: 0.0281 - acc: 0.9500 - val_loss: 0.1459 - val_ac
c: 0.7680
Epoch 141/200
1/1 [==============================] - 0s 194ms/step - loss: 0.0242 - acc: 0.9786 - val_loss: 0.1451 - val_ac
c: 0.7720
Epoch 142/200
```

```
1/1 [==============================] - 0s 196ms/step - loss: 0.0273 - acc: 0.9643 - val_loss: 0.1452 - val_ac
c: 0.7740
Epoch 143/200
1/1 [==============================] - 0s 183ms/step - loss: 0.0262 - acc: 0.9786 - val_loss: 0.1453 - val_ac
c: 0.7760
Epoch 144/200
1/1 [==============================] - 0s 204ms/step - loss: 0.0237 - acc: 0.9929 - val_loss: 0.1452 - val_ac
c: 0.7840
Epoch 145/200
1/1 [==============================] - 0s 191ms/step - loss: 0.0273 - acc: 0.9500 - val_loss: 0.1456 - val_ac
c: 0.7780
Epoch 146/200
1/1 [==============================] - 0s 188ms/step - loss: 0.0246 - acc: 0.9643 - val_loss: 0.1469 - val_ac
c: 0.7800
Epoch 147/200
1/1 [==============================] - 0s 182ms/step - loss: 0.0259 - acc: 0.9643 - val_loss: 0.1480 - val_ac
c: 0.7840
Epoch 148/200
1/1 [==============================] - 0s 186ms/step - loss: 0.0256 - acc: 0.9571 - val_loss: 0.1490 - val_ac
c: 0.7820
Epoch 149/200
1/1 [==============================] - 0s 196ms/step - loss: 0.0251 - acc: 0.9929 - val_loss: 0.1507 - val_ac
c: 0.7760
Epoch 150/200
1/1 [==============================] - 0s 193ms/step - loss: 0.0244 - acc: 0.9857 - val_loss: 0.1525 - val_ac
c: 0.7640
Epoch 151/200
1/1 [==============================] - 0s 191ms/step - loss: 0.0261 - acc: 0.9714 - val_loss: 0.1520 - val_ac
c: 0.7660
Epoch 152/200
1/1 [==============================] - 0s 214ms/step - loss: 0.0246 - acc: 0.9857 - val_loss: 0.1484 - val_ac
c: 0.7720
Epoch 153/200
1/1 [==============================] - 0s 189ms/step - loss: 0.0261 - acc: 0.9714 - val_loss: 0.1450 - val_ac
c: 0.7740
Epoch 154/200
1/1 [==============================] - 0s 195ms/step - loss: 0.0252 - acc: 0.9714 - val_loss: 0.1421 - val_ac
c: 0.7760
Epoch 155/200
1/1 [==============================] - 0s 198ms/step - loss: 0.0236 - acc: 0.9929 - val_loss: 0.1398 - val_ac
c: 0.7840
Epoch 156/200
1/1 [==============================] - 0s 189ms/step - loss: 0.0246 - acc: 0.9786 - val_loss: 0.1395 - val_ac
c: 0.7860
Epoch 157/200
1/1 [==============================] - 0s 197ms/step - loss: 0.0249 - acc: 0.9643 - val_loss: 0.1399 - val_ac
c: 0.7840
Epoch 158/200
1/1 [==============================] - 0s 179ms/step - loss: 0.0228 - acc: 0.9929 - val_loss: 0.1398 - val_ac
c: 0.7860
Epoch 159/200
1/1 [==============================] - 0s 181ms/step - loss: 0.0253 - acc: 0.9857 - val_loss: 0.1416 - val_ac
c: 0.7800
Epoch 160/200
1/1 [==============================] - 0s 194ms/step - loss: 0.0259 - acc: 0.9571 - val_loss: 0.1442 - val_ac
c: 0.7800
Epoch 161/200
1/1 [==============================] - 0s 185ms/step - loss: 0.0234 - acc: 0.9929 - val_loss: 0.1474 - val_ac
c: 0.7820
Epoch 162/200
1/1 [==============================] - 0s 193ms/step - loss: 0.0281 - acc: 0.9500 - val_loss: 0.1481 - val_ac
c: 0.7780
Epoch 163/200
1/1 [==============================] - 0s 209ms/step - loss: 0.0214 - acc: 0.9929 - val_loss: 0.1480 - val_ac
c: 0.7740
Epoch 164/200
1/1 [==============================] - 0s 195ms/step - loss: 0.0251 - acc: 0.9571 - val_loss: 0.1465 - val_ac
c: 0.7740
Epoch 165/200
1/1 [==============================] - 0s 187ms/step - loss: 0.0248 - acc: 0.9714 - val_loss: 0.1473 - val_ac
c: 0.7700
```

```
Epoch 166/200
1/1 [==============================] - 0s 195ms/step - loss: 0.0246 - acc: 0.9714 - val_loss: 0.1473 - val_ac
c: 0.7700
Epoch 167/200
1/1 [==============================] - 0s 188ms/step - loss: 0.0232 - acc: 0.9786 - val_loss: 0.1463 - val_ac
c: 0.7700
Epoch 168/200
1/1 [==============================] - 0s 188ms/step - loss: 0.0244 - acc: 0.9857 - val_loss: 0.1451 - val_ac
c: 0.7780
Epoch 169/200
1/1 [==============================] - 0s 200ms/step - loss: 0.0237 - acc: 0.9857 - val_loss: 0.1454 - val_ac
c: 0.7800
Epoch 170/200
1/1 [==============================] - 0s 212ms/step - loss: 0.0273 - acc: 0.9429 - val_loss: 0.1444 - val_ac
c: 0.7860
Epoch 171/200
1/1 [==============================] - 0s 213ms/step - loss: 0.0231 - acc: 1.0000 - val_loss: 0.1439 - val_ac
c: 0.7860
Epoch 172/200
1/1 [==============================] - 0s 193ms/step - loss: 0.0242 - acc: 0.9714 - val_loss: 0.1442 - val_ac
c: 0.7880
Epoch 173/200
1/1 [==============================] - 0s 208ms/step - loss: 0.0272 - acc: 0.9429 - val_loss: 0.1444 - val_ac
c: 0.7880
Epoch 174/200
1/1 [==============================] - 0s 212ms/step - loss: 0.0215 - acc: 0.9929 - val_loss: 0.1452 - val_ac
c: 0.7880
Epoch 175/200
1/1 [==============================] - 0s 283ms/step - loss: 0.0233 - acc: 0.9929 - val_loss: 0.1469 - val_ac
c: 0.7840
Epoch 176/200
1/1 [==============================] - 0s 196ms/step - loss: 0.0237 - acc: 0.9643 - val_loss: 0.1489 - val_ac
c: 0.7740
Epoch 177/200
1/1 [==============================] - 0s 184ms/step - loss: 0.0234 - acc: 0.9929 - val_loss: 0.1509 - val_ac
c: 0.7700
Epoch 178/200
1/1 [==============================] - 0s 201ms/step - loss: 0.0255 - acc: 0.9643 - val_loss: 0.1508 - val_ac
c: 0.7660
Epoch 179/200
1/1 [==============================] - 0s 188ms/step - loss: 0.0226 - acc: 0.9857 - val_loss: 0.1497 - val_ac
c: 0.7680
Epoch 180/200
1/1 [==============================] - 0s 184ms/step - loss: 0.0224 - acc: 0.9786 - val_loss: 0.1472 - val_ac
c: 0.7740
Epoch 181/200
1/1 [==============================] - 0s 203ms/step - loss: 0.0243 - acc: 0.9643 - val_loss: 0.1448 - val_ac
c: 0.7760
Epoch 182/200
1/1 [==============================] - 0s 233ms/step - loss: 0.0249 - acc: 0.9714 - val_loss: 0.1434 - val_ac
c: 0.7760
Epoch 183/200
1/1 [==============================] - 0s 215ms/step - loss: 0.0227 - acc: 0.9714 - val_loss: 0.1428 - val_ac
c: 0.7780
Epoch 184/200
1/1 [==============================] - 0s 215ms/step - loss: 0.0217 - acc: 0.9929 - val_loss: 0.1422 - val_ac
c: 0.7780
Epoch 185/200
1/1 [==============================] - 0s 230ms/step - loss: 0.0232 - acc: 0.9786 - val_loss: 0.1406 - val_ac
c: 0.7780
Epoch 186/200
1/1 [==============================] - 0s 199ms/step - loss: 0.0220 - acc: 0.9571 - val_loss: 0.1398 - val_ac
c: 0.7840
Epoch 187/200
1/1 [==============================] - 0s 198ms/step - loss: 0.0257 - acc: 0.9857 - val_loss: 0.1384 - val_ac
c: 0.7840
Epoch 188/200
1/1 [==============================] - 0s 225ms/step - loss: 0.0252 - acc: 0.9714 - val_loss: 0.1379 - val_ac
c: 0.7840
Epoch 189/200
1/1 [==============================] - 0s 300ms/step - loss: 0.0232 - acc: 0.9643 - val_loss: 0.1389 - val_ac
```

```
c: 0.7860
Epoch 190/200
1/1 [==============================] - 0s 189ms/step - loss: 0.0215 - acc: 0.9929 - val_loss: 0.1399 - val_ac
c: 0.7920
Epoch 191/200
1/1 [==============================] - 0s 212ms/step - loss: 0.0241 - acc: 0.9643 - val_loss: 0.1410 - val_ac
c: 0.8000
Epoch 192/200
1/1 [==============================] - 0s 190ms/step - loss: 0.0224 - acc: 0.9857 - val_loss: 0.1408 - val_ac
c: 0.8000
Epoch 193/200
1/1 [==============================] - 0s 187ms/step - loss: 0.0222 - acc: 0.9857 - val_loss: 0.1401 - val_ac
c: 0.7980
Epoch 194/200
1/1 [==============================] - 0s 176ms/step - loss: 0.0238 - acc: 0.9786 - val_loss: 0.1403 - val_ac
c: 0.7960
Epoch 195/200
1/1 [==============================] - 0s 184ms/step - loss: 0.0238 - acc: 0.9643 - val_loss: 0.1417 - val_ac
c: 0.7980
Epoch 196/200
1/1 [==============================] - 0s 222ms/step - loss: 0.0224 - acc: 0.9857 - val_loss: 0.1428 - val_ac
c: 0.7940
Epoch 197/200
1/1 [==============================] - 0s 183ms/step - loss: 0.0234 - acc: 0.9714 - val_loss: 0.1435 - val_ac
c: 0.7920
Epoch 198/200
1/1 [==============================] - 0s 172ms/step - loss: 0.0247 - acc: 0.9714 - val_loss: 0.1426 - val_ac
c: 0.7840
Epoch 199/200
1/1 [==============================] - 0s 179ms/step - loss: 0.0238 - acc: 0.9786 - val_loss: 0.1428 - val_ac
c: 0.7820
Epoch 200/200
1/1 [==============================] - 0s 173ms/step - loss: 0.0238 - acc: 0.9643 - val_loss: 0.1442 - val_ac
c: 0.7780
```

Out[ ]: <tensorflow.python.keras.callbacks.History at 0x1da4fbdeec8>

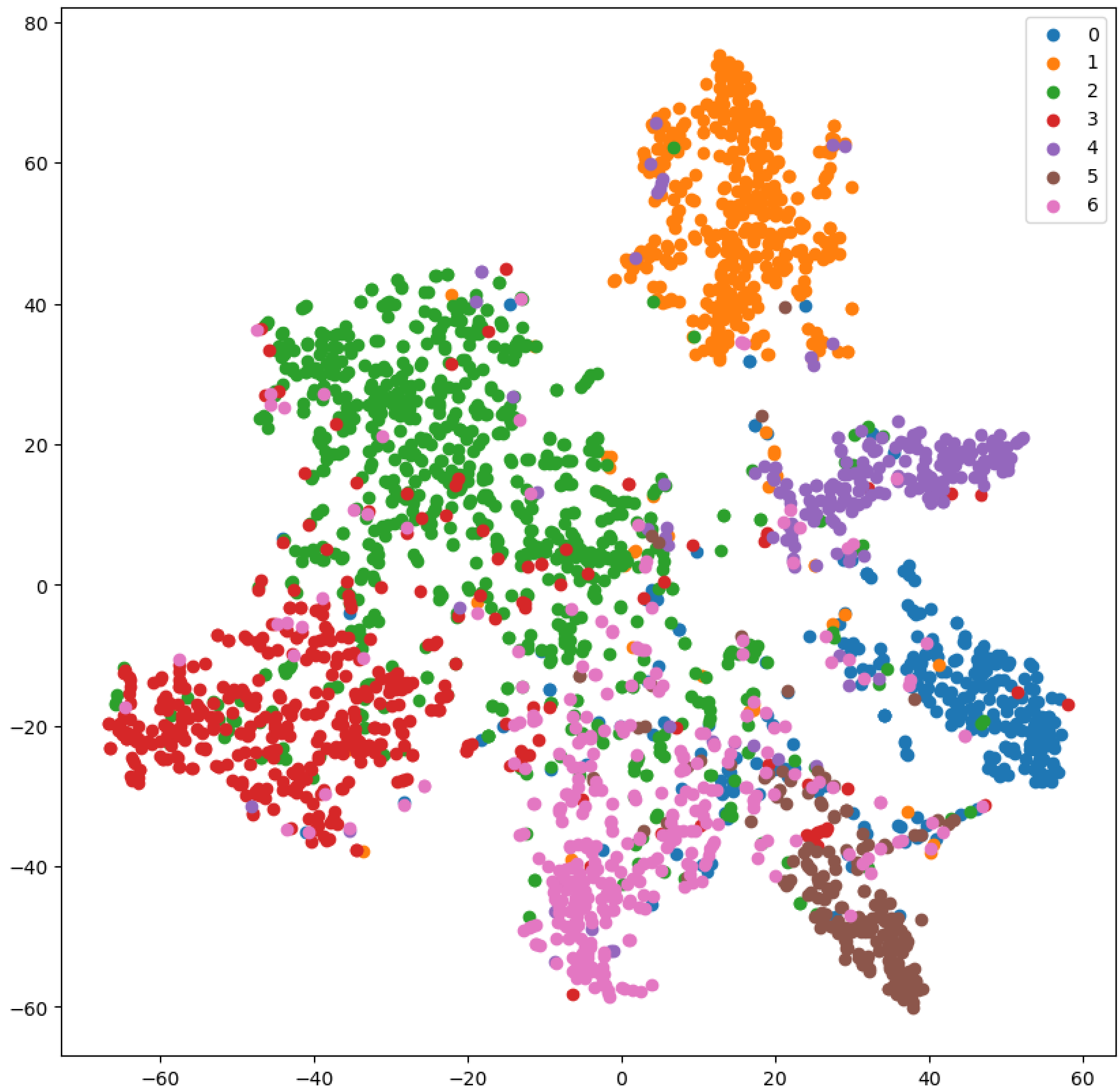
In [ ]:
```
# Evaluate model
X_te = X[test_mask]
A_te = A[test_mask,:][:,test_mask]
y_te = labels_encoded[test_mask]

y_pred = model.predict([X_te, A_te], batch_size=N)
report = classification_report(np.argmax(y_te,axis=1), np.argmax(y_pred,axis=1), target_names=classes)
print('GCN Classification Report: \n {}'.format(report))
```

```
GCN Classification Report:
                         precision    recall  f1-score   support

            Case_Based       0.72      0.79      0.75       114
    Genetic_Algorithms       0.88      0.87      0.87       156
       Neural_Networks       0.79      0.62      0.70       290
 Probabilistic_Methods       0.79      0.69      0.74       172
Reinforcement_Learning       0.63      0.80      0.70        85
         Rule_Learning       0.52      0.77      0.62        60
                Theory       0.53      0.63      0.58       123

              accuracy                           0.72      1000
             macro avg       0.69      0.74      0.71      1000
          weighted avg       0.74      0.72      0.72      1000
```

Get hidden layer representation for GCN

In [ ]:
```
layer_outputs = [layer.output for layer in model.layers]
activation_model = Model(inputs=model.input, outputs=layer_outputs)
activations = activation_model.predict([X,A],batch_size=N)

#Get t-SNE Representation
#get the hidden layer representation after the first GCN layer
x_tsne = TSNE(n_components=2).fit_transform(activations[3])
```

In [ ]:
```
def plot_tSNE(labels_encoded,x_tsne):
    color_map = np.argmax(labels_encoded, axis=1)
    plt.figure(figsize=(10,10))
    for cl in range(num_classes):
        indices = np.where(color_map==cl)
        indices = indices[0]
        plt.scatter(x_tsne[indices,0], x_tsne[indices, 1], label=cl)
    plt.legend()
    plt.show()

plot_tSNE(labels_encoded,x_tsne)
```



Comparison to Fully-Connected Neural Networks

Building and Training FNN

In [ ]:
```
es_patience = 100
optimizer = Adam(lr=1e-2)
l2_reg = 5e-4
epochs = 200
```

```
#Compare with FNN
#Construct the model
model_fnn = Sequential()
model_fnn.add(Dense(
                    128,
                    input_dim=X.shape[1],
                    activation=tf.nn.relu,
                    kernel_regularizer=tf.keras.regularizers.l2(l2_reg))
             )
model_fnn.add(Dropout(0.5))
model_fnn.add(Dense(256, activation=tf.nn.relu))
model_fnn.add(Dropout(0.5))
model_fnn.add(Dense(num_classes, activation=tf.keras.activations.softmax))


model_fnn.compile(optimizer=optimizer,
              loss='categorical_crossentropy',
              weighted_metrics=['acc'])


#define TensorBoard
tbCallBack_FNN = TensorBoard(
    log_dir='./Tensorboard_FNN_cora',
)

#Train model
validation_data_fnn = (X, labels_encoded, val_mask)
model_fnn.fit(
                X,labels_encoded,
                sample_weight=train_mask,
                epochs=epochs,
                batch_size=N,
                validation_data=validation_data_fnn,
                shuffle=False,
                callbacks=[
                  EarlyStopping(patience=es_patience,  restore_best_weights=True),
                  tbCallBack_FNN
          ])
```

```
Epoch 1/200
1/1 [==============================] - 0s 279ms/step - loss: 0.2183 - acc: 0.1357 - val_loss: 0.4331 - val_ac
c: 0.2620
Epoch 2/200
1/1 [==============================] - ETA: 0s - loss: 0.1745 - acc: 0.3714WARNING:tensorflow:Method (on_trai
n_batch_end) is slow compared to the batch update (0.155369). Check your callbacks.
1/1 [==============================] - 0s 183ms/step - loss: 0.1745 - acc: 0.3714 - val_loss: 0.3982 - val_ac
c: 0.3780
Epoch 3/200
1/1 [==============================] - 0s 178ms/step - loss: 0.1408 - acc: 0.5286 - val_loss: 0.3664 - val_ac
c: 0.5100
Epoch 4/200
1/1 [==============================] - 0s 175ms/step - loss: 0.1109 - acc: 0.7286 - val_loss: 0.3330 - val_ac
c: 0.5900
Epoch 5/200
1/1 [==============================] - 0s 240ms/step - loss: 0.0888 - acc: 0.7786 - val_loss: 0.2995 - val_ac
c: 0.5880
Epoch 6/200
1/1 [==============================] - 0s 222ms/step - loss: 0.0647 - acc: 0.8429 - val_loss: 0.2698 - val_ac
c: 0.5980
Epoch 7/200
1/1 [==============================] - 0s 285ms/step - loss: 0.0535 - acc: 0.9071 - val_loss: 0.2639 - val_ac
c: 0.5440
Epoch 8/200
1/1 [==============================] - 0s 257ms/step - loss: 0.0443 - acc: 0.9500 - val_loss: 0.2697 - val_ac
c: 0.5540
Epoch 9/200
1/1 [==============================] - 0s 249ms/step - loss: 0.0440 - acc: 0.9714 - val_loss: 0.2825 - val_ac
c: 0.5580
Epoch 10/200
1/1 [==============================] - 0s 324ms/step - loss: 0.0408 - acc: 0.9786 - val_loss: 0.2914 - val_ac
c: 0.5560
Epoch 11/200
1/1 [==============================] - 0s 334ms/step - loss: 0.0438 - acc: 0.9786 - val_loss: 0.3047 - val_ac
c: 0.5640
Epoch 12/200
1/1 [==============================] - 0s 260ms/step - loss: 0.0412 - acc: 0.9929 - val_loss: 0.3126 - val_ac
c: 0.5700
Epoch 13/200
1/1 [==============================] - 0s 267ms/step - loss: 0.0430 - acc: 0.9786 - val_loss: 0.3161 - val_ac
c: 0.5800
Epoch 14/200
1/1 [==============================] - 0s 257ms/step - loss: 0.0393 - acc: 0.9857 - val_loss: 0.3288 - val_ac
c: 0.5840
Epoch 15/200
1/1 [==============================] - 0s 260ms/step - loss: 0.0359 - acc: 1.0000 - val_loss: 0.3476 - val_ac
c: 0.5780
Epoch 16/200
1/1 [==============================] - 0s 262ms/step - loss: 0.0343 - acc: 0.9929 - val_loss: 0.3653 - val_ac
c: 0.5700
Epoch 17/200
1/1 [==============================] - 0s 295ms/step - loss: 0.0314 - acc: 0.9857 - val_loss: 0.3805 - val_ac
c: 0.5720
Epoch 18/200
1/1 [==============================] - 0s 350ms/step - loss: 0.0295 - acc: 0.9929 - val_loss: 0.3836 - val_ac
c: 0.5700
Epoch 19/200
1/1 [==============================] - 1s 536ms/step - loss: 0.0280 - acc: 0.9786 - val_loss: 0.3876 - val_ac
c: 0.5620
Epoch 20/200
1/1 [==============================] - 0s 365ms/step - loss: 0.0268 - acc: 0.9786 - val_loss: 0.3920 - val_ac
c: 0.5560
Epoch 21/200
1/1 [==============================] - 1s 562ms/step - loss: 0.0235 - acc: 0.9929 - val_loss: 0.3967 - val_ac
c: 0.5380
Epoch 22/200
1/1 [==============================] - 0s 327ms/step - loss: 0.0221 - acc: 0.9929 - val_loss: 0.4062 - val_ac
c: 0.5180
Epoch 23/200
1/1 [==============================] - 0s 273ms/step - loss: 0.0230 - acc: 0.9857 - val_loss: 0.4159 - val_ac
c: 0.5060
```

```
Epoch 24/200
1/1 [==============================] - 0s 270ms/step - loss: 0.0211 - acc: 0.9857 - val_loss: 0.4128 - val_ac
c: 0.4880
Epoch 25/200
1/1 [==============================] - 0s 313ms/step - loss: 0.0201 - acc: 0.9929 - val_loss: 0.3974 - val_ac
c: 0.5040
Epoch 26/200
1/1 [==============================] - 0s 346ms/step - loss: 0.0204 - acc: 0.9857 - val_loss: 0.3827 - val_ac
c: 0.5140
Epoch 27/200
1/1 [==============================] - 0s 284ms/step - loss: 0.0204 - acc: 0.9857 - val_loss: 0.3737 - val_ac
c: 0.5200
Epoch 28/200
1/1 [==============================] - 0s 306ms/step - loss: 0.0198 - acc: 0.9786 - val_loss: 0.3581 - val_ac
c: 0.5200
Epoch 29/200
1/1 [==============================] - 0s 220ms/step - loss: 0.0196 - acc: 0.9929 - val_loss: 0.3571 - val_ac
c: 0.5140
Epoch 30/200
1/1 [==============================] - 0s 253ms/step - loss: 0.0184 - acc: 0.9929 - val_loss: 0.3600 - val_ac
c: 0.5120
Epoch 31/200
1/1 [==============================] - 0s 278ms/step - loss: 0.0201 - acc: 0.9857 - val_loss: 0.3592 - val_ac
c: 0.5140
Epoch 32/200
1/1 [==============================] - 0s 260ms/step - loss: 0.0182 - acc: 0.9929 - val_loss: 0.3577 - val_ac
c: 0.5060
Epoch 33/200
1/1 [==============================] - 0s 277ms/step - loss: 0.0177 - acc: 1.0000 - val_loss: 0.3562 - val_ac
c: 0.5180
Epoch 34/200
1/1 [==============================] - 0s 246ms/step - loss: 0.0194 - acc: 0.9857 - val_loss: 0.3513 - val_ac
c: 0.5220
Epoch 35/200
1/1 [==============================] - 0s 257ms/step - loss: 0.0191 - acc: 0.9857 - val_loss: 0.3404 - val_ac
c: 0.5300
Epoch 36/200
1/1 [==============================] - 0s 286ms/step - loss: 0.0186 - acc: 0.9929 - val_loss: 0.3340 - val_ac
c: 0.5260
Epoch 37/200
1/1 [==============================] - 0s 281ms/step - loss: 0.0204 - acc: 0.9786 - val_loss: 0.3272 - val_ac
c: 0.5460
Epoch 38/200
1/1 [==============================] - 0s 233ms/step - loss: 0.0186 - acc: 0.9929 - val_loss: 0.3233 - val_ac
c: 0.5460
Epoch 39/200
1/1 [==============================] - 0s 246ms/step - loss: 0.0195 - acc: 0.9786 - val_loss: 0.3276 - val_ac
c: 0.5440
Epoch 40/200
1/1 [==============================] - 0s 197ms/step - loss: 0.0189 - acc: 0.9929 - val_loss: 0.3320 - val_ac
c: 0.5540
Epoch 41/200
1/1 [==============================] - 0s 180ms/step - loss: 0.0190 - acc: 0.9929 - val_loss: 0.3387 - val_ac
c: 0.5420
Epoch 42/200
1/1 [==============================] - 0s 191ms/step - loss: 0.0189 - acc: 0.9929 - val_loss: 0.3466 - val_ac
c: 0.5360
Epoch 43/200
1/1 [==============================] - 0s 189ms/step - loss: 0.0208 - acc: 0.9714 - val_loss: 0.3581 - val_ac
c: 0.5240
Epoch 44/200
1/1 [==============================] - 0s 180ms/step - loss: 0.0175 - acc: 1.0000 - val_loss: 0.3668 - val_ac
c: 0.5180
Epoch 45/200
1/1 [==============================] - 0s 174ms/step - loss: 0.0187 - acc: 0.9857 - val_loss: 0.3669 - val_ac
c: 0.5180
Epoch 46/200
1/1 [==============================] - 0s 173ms/step - loss: 0.0172 - acc: 1.0000 - val_loss: 0.3703 - val_ac
c: 0.5220
Epoch 47/200
1/1 [==============================] - 0s 169ms/step - loss: 0.0178 - acc: 0.9929 - val_loss: 0.3731 - val_ac
```

```
c: 0.5200
Epoch 48/200
1/1 [==============================] - 0s 168ms/step - loss: 0.0175 - acc: 0.9857 - val_loss: 0.3703 - val_ac
c: 0.5220
Epoch 49/200
1/1 [==============================] - 0s 169ms/step - loss: 0.0162 - acc: 1.0000 - val_loss: 0.3664 - val_ac
c: 0.5280
Epoch 50/200
1/1 [==============================] - 0s 172ms/step - loss: 0.0159 - acc: 1.0000 - val_loss: 0.3673 - val_ac
c: 0.5180
Epoch 51/200
1/1 [==============================] - 0s 166ms/step - loss: 0.0187 - acc: 0.9786 - val_loss: 0.3701 - val_ac
c: 0.5140
Epoch 52/200
1/1 [==============================] - 0s 158ms/step - loss: 0.0155 - acc: 1.0000 - val_loss: 0.3745 - val_ac
c: 0.5120
Epoch 53/200
1/1 [==============================] - 0s 185ms/step - loss: 0.0162 - acc: 1.0000 - val_loss: 0.3703 - val_ac
c: 0.5300
Epoch 54/200
1/1 [==============================] - 0s 170ms/step - loss: 0.0179 - acc: 0.9714 - val_loss: 0.3793 - val_ac
c: 0.5180
Epoch 55/200
1/1 [==============================] - 0s 166ms/step - loss: 0.0160 - acc: 0.9857 - val_loss: 0.3840 - val_ac
c: 0.5160
Epoch 56/200
1/1 [==============================] - 0s 221ms/step - loss: 0.0162 - acc: 0.9857 - val_loss: 0.3856 - val_ac
c: 0.5060
Epoch 57/200
1/1 [==============================] - 0s 176ms/step - loss: 0.0157 - acc: 0.9929 - val_loss: 0.3776 - val_ac
c: 0.5020
Epoch 58/200
1/1 [==============================] - 0s 155ms/step - loss: 0.0187 - acc: 0.9786 - val_loss: 0.3614 - val_ac
c: 0.5060
Epoch 59/200
1/1 [==============================] - 0s 159ms/step - loss: 0.0172 - acc: 0.9786 - val_loss: 0.3485 - val_ac
c: 0.5000
Epoch 60/200
1/1 [==============================] - 0s 153ms/step - loss: 0.0156 - acc: 0.9929 - val_loss: 0.3475 - val_ac
c: 0.5060
Epoch 61/200
1/1 [==============================] - 0s 157ms/step - loss: 0.0177 - acc: 0.9714 - val_loss: 0.3368 - val_ac
c: 0.5220
Epoch 62/200
1/1 [==============================] - 0s 157ms/step - loss: 0.0198 - acc: 0.9786 - val_loss: 0.3303 - val_ac
c: 0.5280
Epoch 63/200
1/1 [==============================] - 0s 191ms/step - loss: 0.0173 - acc: 1.0000 - val_loss: 0.3396 - val_ac
c: 0.5240
Epoch 64/200
1/1 [==============================] - 0s 207ms/step - loss: 0.0173 - acc: 0.9929 - val_loss: 0.3642 - val_ac
c: 0.5080
Epoch 65/200
1/1 [==============================] - 0s 200ms/step - loss: 0.0208 - acc: 0.9714 - val_loss: 0.4034 - val_ac
c: 0.4920
Epoch 66/200
1/1 [==============================] - 0s 193ms/step - loss: 0.0212 - acc: 0.9857 - val_loss: 0.4225 - val_ac
c: 0.4960
Epoch 67/200
1/1 [==============================] - 0s 166ms/step - loss: 0.0209 - acc: 0.9786 - val_loss: 0.4260 - val_ac
c: 0.4940
Epoch 68/200
1/1 [==============================] - 0s 162ms/step - loss: 0.0204 - acc: 1.0000 - val_loss: 0.4359 - val_ac
c: 0.4920
Epoch 69/200
1/1 [==============================] - 0s 160ms/step - loss: 0.0216 - acc: 0.9857 - val_loss: 0.4449 - val_ac
c: 0.4880
Epoch 70/200
1/1 [==============================] - 0s 158ms/step - loss: 0.0265 - acc: 0.9786 - val_loss: 0.4416 - val_ac
c: 0.4860
Epoch 71/200
```

```
1/1 [==============================] - 0s 160ms/step - loss: 0.0241 - acc: 0.9857 - val_loss: 0.4469 - val_ac
c: 0.4800
Epoch 72/200
1/1 [==============================] - 0s 164ms/step - loss: 0.0221 - acc: 0.9929 - val_loss: 0.4479 - val_ac
c: 0.4780
Epoch 73/200
1/1 [==============================] - 0s 163ms/step - loss: 0.0245 - acc: 0.9786 - val_loss: 0.4391 - val_ac
c: 0.4680
Epoch 74/200
1/1 [==============================] - 0s 179ms/step - loss: 0.0276 - acc: 0.9714 - val_loss: 0.4323 - val_ac
c: 0.4700
Epoch 75/200
1/1 [==============================] - 0s 182ms/step - loss: 0.0240 - acc: 0.9786 - val_loss: 0.4211 - val_ac
c: 0.4840
Epoch 76/200
1/1 [==============================] - 0s 176ms/step - loss: 0.0287 - acc: 0.9643 - val_loss: 0.4028 - val_ac
c: 0.4800
Epoch 77/200
1/1 [==============================] - 0s 215ms/step - loss: 0.0271 - acc: 0.9714 - val_loss: 0.3904 - val_ac
c: 0.4780
Epoch 78/200
1/1 [==============================] - 0s 174ms/step - loss: 0.0237 - acc: 1.0000 - val_loss: 0.3874 - val_ac
c: 0.4840
Epoch 79/200
1/1 [==============================] - 0s 190ms/step - loss: 0.0292 - acc: 0.9643 - val_loss: 0.3887 - val_ac
c: 0.4820
Epoch 80/200
1/1 [==============================] - 0s 197ms/step - loss: 0.0259 - acc: 0.9929 - val_loss: 0.3893 - val_ac
c: 0.4920
Epoch 81/200
1/1 [==============================] - 0s 205ms/step - loss: 0.0253 - acc: 1.0000 - val_loss: 0.3888 - val_ac
c: 0.4960
Epoch 82/200
1/1 [==============================] - 0s 185ms/step - loss: 0.0252 - acc: 1.0000 - val_loss: 0.3881 - val_ac
c: 0.4980
Epoch 83/200
1/1 [==============================] - 0s 171ms/step - loss: 0.0270 - acc: 0.9857 - val_loss: 0.3915 - val_ac
c: 0.5120
Epoch 84/200
1/1 [==============================] - 0s 188ms/step - loss: 0.0264 - acc: 0.9857 - val_loss: 0.3995 - val_ac
c: 0.5160
Epoch 85/200
1/1 [==============================] - 0s 177ms/step - loss: 0.0273 - acc: 0.9714 - val_loss: 0.4138 - val_ac
c: 0.5080
Epoch 86/200
1/1 [==============================] - 0s 187ms/step - loss: 0.0271 - acc: 0.9929 - val_loss: 0.4144 - val_ac
c: 0.5200
Epoch 87/200
1/1 [==============================] - 0s 203ms/step - loss: 0.0266 - acc: 0.9929 - val_loss: 0.4101 - val_ac
c: 0.5240
Epoch 88/200
1/1 [==============================] - 0s 200ms/step - loss: 0.0269 - acc: 0.9929 - val_loss: 0.4038 - val_ac
c: 0.5320
Epoch 89/200
1/1 [==============================] - 0s 207ms/step - loss: 0.0260 - acc: 0.9929 - val_loss: 0.4009 - val_ac
c: 0.5240
Epoch 90/200
1/1 [==============================] - 0s 206ms/step - loss: 0.0270 - acc: 0.9857 - val_loss: 0.4036 - val_ac
c: 0.5100
Epoch 91/200
1/1 [==============================] - 0s 219ms/step - loss: 0.0258 - acc: 0.9929 - val_loss: 0.4085 - val_ac
c: 0.4980
Epoch 92/200
1/1 [==============================] - 0s 199ms/step - loss: 0.0274 - acc: 0.9714 - val_loss: 0.4255 - val_ac
c: 0.4900
Epoch 93/200
1/1 [==============================] - 0s 273ms/step - loss: 0.0260 - acc: 0.9857 - val_loss: 0.4271 - val_ac
c: 0.4840
Epoch 94/200
1/1 [==============================] - 0s 199ms/step - loss: 0.0260 - acc: 0.9786 - val_loss: 0.4209 - val_ac
c: 0.4900
```

```
Epoch 95/200
1/1 [==============================] - 0s 183ms/step - loss: 0.0252 - acc: 0.9786 - val_loss: 0.4151 - val_ac
c: 0.4940
Epoch 96/200
1/1 [==============================] - 0s 181ms/step - loss: 0.0232 - acc: 1.0000 - val_loss: 0.4128 - val_ac
c: 0.4780
Epoch 97/200
1/1 [==============================] - 0s 205ms/step - loss: 0.0240 - acc: 0.9929 - val_loss: 0.4139 - val_ac
c: 0.4840
Epoch 98/200
1/1 [==============================] - 0s 183ms/step - loss: 0.0239 - acc: 0.9929 - val_loss: 0.4195 - val_ac
c: 0.4760
Epoch 99/200
1/1 [==============================] - 0s 196ms/step - loss: 0.0249 - acc: 0.9786 - val_loss: 0.4278 - val_ac
c: 0.4640
Epoch 100/200
1/1 [==============================] - 0s 203ms/step - loss: 0.0278 - acc: 0.9643 - val_loss: 0.4342 - val_ac
c: 0.4640
Epoch 101/200
1/1 [==============================] - 0s 206ms/step - loss: 0.0246 - acc: 0.9857 - val_loss: 0.4293 - val_ac
c: 0.4580
Epoch 102/200
1/1 [==============================] - 0s 177ms/step - loss: 0.0258 - acc: 0.9714 - val_loss: 0.4192 - val_ac
c: 0.4600
Epoch 103/200
1/1 [==============================] - 0s 200ms/step - loss: 0.0230 - acc: 1.0000 - val_loss: 0.4141 - val_ac
c: 0.4580
Epoch 104/200
1/1 [==============================] - 0s 190ms/step - loss: 0.0314 - acc: 0.9571 - val_loss: 0.4100 - val_ac
c: 0.4640
Epoch 105/200
1/1 [==============================] - 0s 201ms/step - loss: 0.0280 - acc: 0.9643 - val_loss: 0.3893 - val_ac
c: 0.4720
Epoch 106/200
1/1 [==============================] - 0s 172ms/step - loss: 0.0249 - acc: 0.9857 - val_loss: 0.3724 - val_ac
c: 0.4900
Epoch 107/200
1/1 [==============================] - 0s 174ms/step - loss: 0.0269 - acc: 0.9857 - val_loss: 0.3630 - val_ac
c: 0.5120
```

Out[ ]:
```
<tensorflow.python.keras.callbacks.History at 0x1da5dc56f88>
```

In [ ]:
```python
# Evaluate model
y_pred = model_fnn.predict(X_te)
report = classification_report(np.argmax(y_te,axis=1), np.argmax(y_pred,axis=1), target_names=classes)
print('FCNN Classification Report: \n {}'.format(report))
```

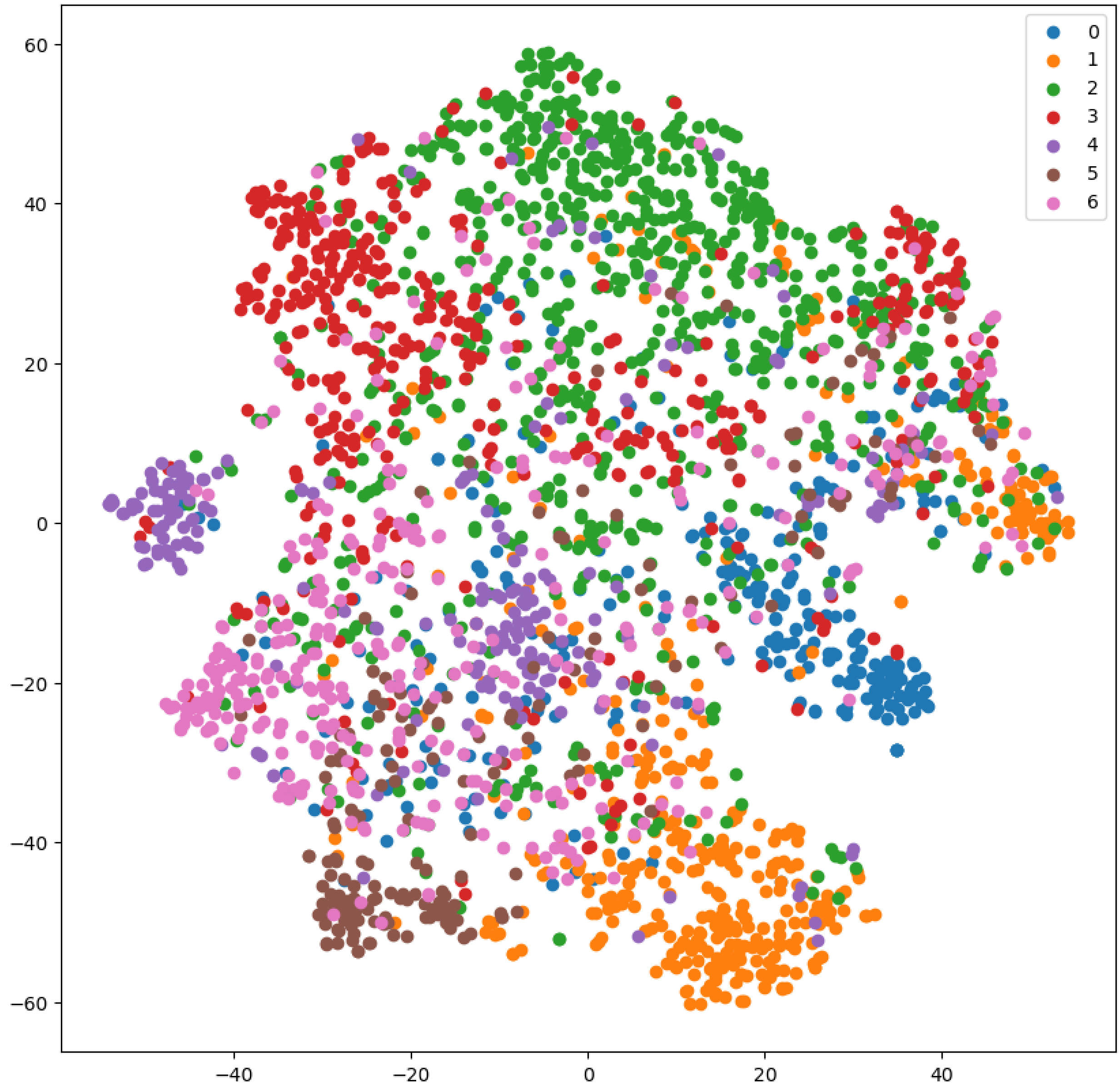
```
FCNN Classification Report: 
                         precision    recall  f1-score   support

            Case_Based       0.63      0.48      0.55       114
    Genetic_Algorithms       0.69      0.75      0.72       156
       Neural_Networks       0.73      0.46      0.56       290
Probabilistic_Methods       0.68      0.52      0.59       172
Reinforcement_Learning       0.32      0.56      0.41        85
         Rule_Learning       0.46      0.57      0.51        60
                Theory       0.36      0.62      0.46       123

              accuracy                           0.55      1000
             macro avg       0.55      0.57      0.54      1000
          weighted avg       0.61      0.55      0.56      1000
```

Get hidden layer representation for FNN

In [ ]:
```python
layer_outputs = [layer.output for layer in model_fnn.layers]
activation_model = Model(inputs=model_fnn.input, outputs=layer_outputs)
activations = activation_model.predict([X])
```

In [ ]:
```python
x_tsne = TSNE(n_components=2).fit_transform(activations[3])
```

```
plot_tSNE(labels_encoded,x_tsne)
```



In [ ]:
```
### END OF NOTEBOOK ###
```