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:  {'Theory', 'Neural_Networks', 'Rule_Learning', 'Genetic_Algorithms', 'Probabilistic_Methods', 'C
ase_Based', 'Reinforcement_Learning'}

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 = 300            # Number of training epochs
es_patience = 150        # 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 1/300
1/1 [==============================] - 0s 345ms/step - loss: 0.1168 - acc: 0.1286 - val_loss: 0.3655 - val_ac
c: 0.1780
Epoch 2/300
1/1 [==============================] - ETA: 0s - loss: 0.1097 - acc: 0.2214WARNING:tensorflow:Method (on_trai
n_batch_end) is slow compared to the batch update (0.169520). Check your callbacks.
1/1 [==============================] - 0s 169ms/step - loss: 0.1097 - acc: 0.2214 - val_loss: 0.3561 - val_ac
c: 0.2380
Epoch 3/300
1/1 [==============================] - 0s 184ms/step - loss: 0.1029 - acc: 0.3214 - val_loss: 0.3465 - val_ac
c: 0.2640
Epoch 4/300
1/1 [==============================] - 0s 173ms/step - loss: 0.0969 - acc: 0.4214 - val_loss: 0.3370 - val_ac
c: 0.2860
Epoch 5/300
1/1 [==============================] - 0s 173ms/step - loss: 0.0929 - acc: 0.4071 - val_loss: 0.3274 - val_ac
c: 0.3380
Epoch 6/300
1/1 [==============================] - 0s 180ms/step - loss: 0.0877 - acc: 0.5000 - val_loss: 0.3177 - val_ac
c: 0.4080
Epoch 7/300
1/1 [==============================] - 0s 170ms/step - loss: 0.0837 - acc: 0.5857 - val_loss: 0.3084 - val_ac
c: 0.4960
Epoch 8/300
1/1 [==============================] - 0s 170ms/step - loss: 0.0822 - acc: 0.6357 - val_loss: 0.2993 - val_ac
c: 0.5780
Epoch 9/300
1/1 [==============================] - 0s 170ms/step - loss: 0.0790 - acc: 0.7071 - val_loss: 0.2905 - val_ac
c: 0.6360
Epoch 10/300
1/1 [==============================] - 0s 235ms/step - loss: 0.0753 - acc: 0.8071 - val_loss: 0.2820 - val_ac
c: 0.6920
Epoch 11/300
1/1 [==============================] - 0s 264ms/step - loss: 0.0754 - acc: 0.7571 - val_loss: 0.2741 - val_ac
c: 0.7280
Epoch 12/300
1/1 [==============================] - 0s 307ms/step - loss: 0.0727 - acc: 0.8714 - val_loss: 0.2664 - val_ac
c: 0.7480
Epoch 13/300
1/1 [==============================] - 0s 238ms/step - loss: 0.0708 - acc: 0.8214 - val_loss: 0.2593 - val_ac
c: 0.7540
Epoch 14/300
1/1 [==============================] - 0s 355ms/step - loss: 0.0690 - acc: 0.8714 - val_loss: 0.2528 - val_ac
c: 0.7600
Epoch 15/300
1/1 [==============================] - 0s 291ms/step - loss: 0.0661 - acc: 0.8929 - val_loss: 0.2465 - val_ac
c: 0.7660
Epoch 16/300
1/1 [==============================] - 0s 213ms/step - loss: 0.0652 - acc: 0.9500 - val_loss: 0.2408 - val_ac
c: 0.7640
Epoch 17/300
1/1 [==============================] - 0s 248ms/step - loss: 0.0645 - acc: 0.9071 - val_loss: 0.2356 - val_ac
c: 0.7660
Epoch 18/300
1/1 [==============================] - 0s 252ms/step - loss: 0.0632 - acc: 0.9071 - val_loss: 0.2310 - val_ac
c: 0.7700
Epoch 19/300
1/1 [==============================] - 0s 436ms/step - loss: 0.0614 - acc: 0.9143 - val_loss: 0.2266 - val_ac
c: 0.7740
Epoch 20/300
1/1 [==============================] - 0s 292ms/step - loss: 0.0628 - acc: 0.8929 - val_loss: 0.2223 - val_ac
c: 0.7740
Epoch 21/300
1/1 [==============================] - 0s 285ms/step - loss: 0.0578 - acc: 0.9143 - val_loss: 0.2185 - val_ac
c: 0.7760
Epoch 22/300
1/1 [==============================] - 0s 243ms/step - loss: 0.0571 - acc: 0.8786 - val_loss: 0.2153 - val_ac
c: 0.7720
Epoch 23/300
1/1 [==============================] - 0s 223ms/step - loss: 0.0560 - acc: 0.9286 - val_loss: 0.2121 - val_ac
c: 0.7760
```

```
Epoch 24/300
1/1 [==============================] - 0s 237ms/step - loss: 0.0542 - acc: 0.9286 - val_loss: 0.2094 - val_ac
c: 0.7740
Epoch 25/300
1/1 [==============================] - 0s 286ms/step - loss: 0.0524 - acc: 0.9286 - val_loss: 0.2068 - val_ac
c: 0.7800
Epoch 26/300
1/1 [==============================] - 0s 390ms/step - loss: 0.0546 - acc: 0.9214 - val_loss: 0.2042 - val_ac
c: 0.7800
Epoch 27/300
1/1 [==============================] - 0s 276ms/step - loss: 0.0540 - acc: 0.9071 - val_loss: 0.2018 - val_ac
c: 0.7800
Epoch 28/300
1/1 [==============================] - 0s 252ms/step - loss: 0.0506 - acc: 0.9357 - val_loss: 0.1996 - val_ac
c: 0.7800
Epoch 29/300
1/1 [==============================] - 0s 246ms/step - loss: 0.0500 - acc: 0.9429 - val_loss: 0.1972 - val_ac
c: 0.7800
Epoch 30/300
1/1 [==============================] - 0s 214ms/step - loss: 0.0492 - acc: 0.9214 - val_loss: 0.1949 - val_ac
c: 0.7800
Epoch 31/300
1/1 [==============================] - 0s 221ms/step - loss: 0.0490 - acc: 0.9500 - val_loss: 0.1924 - val_ac
c: 0.7820
Epoch 32/300
1/1 [==============================] - 0s 234ms/step - loss: 0.0488 - acc: 0.9214 - val_loss: 0.1902 - val_ac
c: 0.7880
Epoch 33/300
1/1 [==============================] - 0s 218ms/step - loss: 0.0480 - acc: 0.9571 - val_loss: 0.1880 - val_ac
c: 0.7860
Epoch 34/300
1/1 [==============================] - 0s 202ms/step - loss: 0.0497 - acc: 0.9286 - val_loss: 0.1864 - val_ac
c: 0.7840
Epoch 35/300
1/1 [==============================] - 0s 247ms/step - loss: 0.0456 - acc: 0.9000 - val_loss: 0.1850 - val_ac
c: 0.7860
Epoch 36/300
1/1 [==============================] - 0s 213ms/step - loss: 0.0444 - acc: 0.9500 - val_loss: 0.1841 - val_ac
c: 0.7860
Epoch 37/300
1/1 [==============================] - 0s 223ms/step - loss: 0.0442 - acc: 0.9500 - val_loss: 0.1831 - val_ac
c: 0.7840
Epoch 38/300
1/1 [==============================] - 0s 216ms/step - loss: 0.0440 - acc: 0.9500 - val_loss: 0.1824 - val_ac
c: 0.7780
Epoch 39/300
1/1 [==============================] - 0s 204ms/step - loss: 0.0412 - acc: 0.9857 - val_loss: 0.1821 - val_ac
c: 0.7800
Epoch 40/300
1/1 [==============================] - 0s 178ms/step - loss: 0.0458 - acc: 0.9071 - val_loss: 0.1811 - val_ac
c: 0.7840
Epoch 41/300
1/1 [==============================] - 0s 174ms/step - loss: 0.0413 - acc: 0.9357 - val_loss: 0.1794 - val_ac
c: 0.7840
Epoch 42/300
1/1 [==============================] - 0s 180ms/step - loss: 0.0431 - acc: 0.9357 - val_loss: 0.1777 - val_ac
c: 0.7820
Epoch 43/300
1/1 [==============================] - 0s 190ms/step - loss: 0.0430 - acc: 0.9286 - val_loss: 0.1761 - val_ac
c: 0.7720
Epoch 44/300
1/1 [==============================] - 0s 180ms/step - loss: 0.0405 - acc: 0.9714 - val_loss: 0.1746 - val_ac
c: 0.7760
Epoch 45/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0411 - acc: 0.9643 - val_loss: 0.1740 - val_ac
c: 0.7740
Epoch 46/300
1/1 [==============================] - 0s 174ms/step - loss: 0.0398 - acc: 0.9571 - val_loss: 0.1737 - val_ac
c: 0.7740
Epoch 47/300
1/1 [==============================] - 0s 196ms/step - loss: 0.0398 - acc: 0.9357 - val_loss: 0.1723 - val_ac
```

```
c: 0.7780
Epoch 48/300
1/1 [==============================] - 0s 210ms/step - loss: 0.0393 - acc: 0.9500 - val_loss: 0.1709 - val_ac
c: 0.7800
Epoch 49/300
1/1 [==============================] - 0s 224ms/step - loss: 0.0380 - acc: 0.9214 - val_loss: 0.1696 - val_ac
c: 0.7840
Epoch 50/300
1/1 [==============================] - 0s 257ms/step - loss: 0.0385 - acc: 0.9643 - val_loss: 0.1691 - val_ac
c: 0.7940
Epoch 51/300
1/1 [==============================] - 0s 190ms/step - loss: 0.0391 - acc: 0.9500 - val_loss: 0.1701 - val_ac
c: 0.7800
Epoch 52/300
1/1 [==============================] - 0s 192ms/step - loss: 0.0394 - acc: 0.9500 - val_loss: 0.1710 - val_ac
c: 0.7820
Epoch 53/300
1/1 [==============================] - 0s 175ms/step - loss: 0.0393 - acc: 0.9714 - val_loss: 0.1709 - val_ac
c: 0.7840
Epoch 54/300
1/1 [==============================] - 0s 181ms/step - loss: 0.0393 - acc: 0.9429 - val_loss: 0.1701 - val_ac
c: 0.7800
Epoch 55/300
1/1 [==============================] - 0s 165ms/step - loss: 0.0384 - acc: 0.9286 - val_loss: 0.1694 - val_ac
c: 0.7760
Epoch 56/300
1/1 [==============================] - 0s 175ms/step - loss: 0.0355 - acc: 0.9643 - val_loss: 0.1691 - val_ac
c: 0.7680
Epoch 57/300
1/1 [==============================] - 0s 171ms/step - loss: 0.0390 - acc: 0.9571 - val_loss: 0.1682 - val_ac
c: 0.7660
Epoch 58/300
1/1 [==============================] - 0s 176ms/step - loss: 0.0360 - acc: 0.9429 - val_loss: 0.1677 - val_ac
c: 0.7680
Epoch 59/300
1/1 [==============================] - 0s 177ms/step - loss: 0.0397 - acc: 0.9643 - val_loss: 0.1669 - val_ac
c: 0.7720
Epoch 60/300
1/1 [==============================] - 0s 180ms/step - loss: 0.0355 - acc: 0.9643 - val_loss: 0.1660 - val_ac
c: 0.7700
Epoch 61/300
1/1 [==============================] - 0s 170ms/step - loss: 0.0378 - acc: 0.9643 - val_loss: 0.1646 - val_ac
c: 0.7720
Epoch 62/300
1/1 [==============================] - 0s 171ms/step - loss: 0.0359 - acc: 0.9429 - val_loss: 0.1630 - val_ac
c: 0.7740
Epoch 63/300
1/1 [==============================] - 0s 171ms/step - loss: 0.0345 - acc: 0.9571 - val_loss: 0.1620 - val_ac
c: 0.7740
Epoch 64/300
1/1 [==============================] - 0s 170ms/step - loss: 0.0349 - acc: 0.9500 - val_loss: 0.1605 - val_ac
c: 0.7840
Epoch 65/300
1/1 [==============================] - 0s 167ms/step - loss: 0.0345 - acc: 0.9714 - val_loss: 0.1599 - val_ac
c: 0.7860
Epoch 66/300
1/1 [==============================] - 0s 163ms/step - loss: 0.0359 - acc: 0.9500 - val_loss: 0.1593 - val_ac
c: 0.7880
Epoch 67/300
1/1 [==============================] - 0s 164ms/step - loss: 0.0376 - acc: 0.9357 - val_loss: 0.1589 - val_ac
c: 0.7880
Epoch 68/300
1/1 [==============================] - 0s 181ms/step - loss: 0.0346 - acc: 0.9143 - val_loss: 0.1595 - val_ac
c: 0.7820
Epoch 69/300
1/1 [==============================] - 0s 180ms/step - loss: 0.0346 - acc: 0.9714 - val_loss: 0.1598 - val_ac
c: 0.7760
Epoch 70/300
1/1 [==============================] - 0s 169ms/step - loss: 0.0365 - acc: 0.9500 - val_loss: 0.1606 - val_ac
c: 0.7720
Epoch 71/300
```

```
1/1 [==============================] - 0s 163ms/step - loss: 0.0353 - acc: 0.9429 - val_loss: 0.1613 - val_ac
c: 0.7740
Epoch 72/300
1/1 [==============================] - 0s 195ms/step - loss: 0.0349 - acc: 0.9929 - val_loss: 0.1608 - val_ac
c: 0.7720
Epoch 73/300
1/1 [==============================] - 0s 268ms/step - loss: 0.0345 - acc: 0.9571 - val_loss: 0.1592 - val_ac
c: 0.7740
Epoch 74/300
1/1 [==============================] - 0s 224ms/step - loss: 0.0296 - acc: 0.9714 - val_loss: 0.1583 - val_ac
c: 0.7800
Epoch 75/300
1/1 [==============================] - 0s 188ms/step - loss: 0.0335 - acc: 0.9714 - val_loss: 0.1589 - val_ac
c: 0.7800
Epoch 76/300
1/1 [==============================] - 0s 190ms/step - loss: 0.0335 - acc: 0.9357 - val_loss: 0.1589 - val_ac
c: 0.7880
Epoch 77/300
1/1 [==============================] - 0s 179ms/step - loss: 0.0290 - acc: 1.0000 - val_loss: 0.1585 - val_ac
c: 0.7900
Epoch 78/300
1/1 [==============================] - 0s 176ms/step - loss: 0.0365 - acc: 0.9714 - val_loss: 0.1591 - val_ac
c: 0.7940
Epoch 79/300
1/1 [==============================] - 0s 158ms/step - loss: 0.0337 - acc: 0.9571 - val_loss: 0.1596 - val_ac
c: 0.7880
Epoch 80/300
1/1 [==============================] - 0s 167ms/step - loss: 0.0341 - acc: 0.9429 - val_loss: 0.1597 - val_ac
c: 0.7860
Epoch 81/300
1/1 [==============================] - 0s 159ms/step - loss: 0.0305 - acc: 0.9857 - val_loss: 0.1599 - val_ac
c: 0.7840
Epoch 82/300
1/1 [==============================] - 0s 159ms/step - loss: 0.0312 - acc: 0.9786 - val_loss: 0.1594 - val_ac
c: 0.7840
Epoch 83/300
1/1 [==============================] - 0s 168ms/step - loss: 0.0289 - acc: 0.9857 - val_loss: 0.1585 - val_ac
c: 0.7820
Epoch 84/300
1/1 [==============================] - 0s 164ms/step - loss: 0.0319 - acc: 0.9571 - val_loss: 0.1577 - val_ac
c: 0.7820
Epoch 85/300
1/1 [==============================] - 0s 168ms/step - loss: 0.0333 - acc: 0.9357 - val_loss: 0.1565 - val_ac
c: 0.7860
Epoch 86/300
1/1 [==============================] - 0s 168ms/step - loss: 0.0317 - acc: 0.9714 - val_loss: 0.1552 - val_ac
c: 0.7860
Epoch 87/300
1/1 [==============================] - 0s 169ms/step - loss: 0.0312 - acc: 0.9857 - val_loss: 0.1542 - val_ac
c: 0.7860
Epoch 88/300
1/1 [==============================] - 0s 187ms/step - loss: 0.0298 - acc: 0.9714 - val_loss: 0.1544 - val_ac
c: 0.7860
Epoch 89/300
1/1 [==============================] - 0s 213ms/step - loss: 0.0296 - acc: 0.9714 - val_loss: 0.1558 - val_ac
c: 0.7860
Epoch 90/300
1/1 [==============================] - 0s 185ms/step - loss: 0.0321 - acc: 0.9429 - val_loss: 0.1571 - val_ac
c: 0.7820
Epoch 91/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0321 - acc: 0.9500 - val_loss: 0.1574 - val_ac
c: 0.7840
Epoch 92/300
1/1 [==============================] - 0s 173ms/step - loss: 0.0300 - acc: 0.9643 - val_loss: 0.1583 - val_ac
c: 0.7880
Epoch 93/300
1/1 [==============================] - 0s 202ms/step - loss: 0.0311 - acc: 0.9643 - val_loss: 0.1568 - val_ac
c: 0.7860
Epoch 94/300
1/1 [==============================] - 0s 177ms/step - loss: 0.0311 - acc: 0.9643 - val_loss: 0.1551 - val_ac
c: 0.7840
```

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Epoch 95/300
1/1 [==============================] - 0s 169ms/step - loss: 0.0279 - acc: 0.9857 - val_loss: 0.1526 - val_ac
c: 0.7880
Epoch 96/300
1/1 [==============================] - 0s 165ms/step - loss: 0.0292 - acc: 0.9500 - val_loss: 0.1491 - val_ac
c: 0.7900
Epoch 97/300
1/1 [==============================] - 0s 190ms/step - loss: 0.0297 - acc: 0.9500 - val_loss: 0.1472 - val_ac
c: 0.7920
Epoch 98/300
1/1 [==============================] - 0s 184ms/step - loss: 0.0292 - acc: 0.9714 - val_loss: 0.1465 - val_ac
c: 0.7900
Epoch 99/300
1/1 [==============================] - 0s 169ms/step - loss: 0.0306 - acc: 0.9714 - val_loss: 0.1469 - val_ac
c: 0.7820
Epoch 100/300
1/1 [==============================] - 0s 169ms/step - loss: 0.0305 - acc: 0.9786 - val_loss: 0.1480 - val_ac
c: 0.7720
Epoch 101/300
1/1 [==============================] - 0s 180ms/step - loss: 0.0325 - acc: 0.9643 - val_loss: 0.1493 - val_ac
c: 0.7700
Epoch 102/300
1/1 [==============================] - 0s 192ms/step - loss: 0.0323 - acc: 0.9571 - val_loss: 0.1506 - val_ac
c: 0.7700
Epoch 103/300
1/1 [==============================] - 0s 177ms/step - loss: 0.0302 - acc: 0.9429 - val_loss: 0.1516 - val_ac
c: 0.7740
Epoch 104/300
1/1 [==============================] - 0s 171ms/step - loss: 0.0284 - acc: 0.9643 - val_loss: 0.1527 - val_ac
c: 0.7620
Epoch 105/300
1/1 [==============================] - 0s 171ms/step - loss: 0.0277 - acc: 0.9857 - val_loss: 0.1527 - val_ac
c: 0.7600
Epoch 106/300
1/1 [==============================] - 0s 171ms/step - loss: 0.0301 - acc: 0.9786 - val_loss: 0.1522 - val_ac
c: 0.7660
Epoch 107/300
1/1 [==============================] - 0s 167ms/step - loss: 0.0283 - acc: 0.9786 - val_loss: 0.1517 - val_ac
c: 0.7800
Epoch 108/300
1/1 [==============================] - 0s 166ms/step - loss: 0.0289 - acc: 0.9714 - val_loss: 0.1519 - val_ac
c: 0.7760
Epoch 109/300
1/1 [==============================] - 0s 169ms/step - loss: 0.0290 - acc: 0.9643 - val_loss: 0.1543 - val_ac
c: 0.7680
Epoch 110/300
1/1 [==============================] - 0s 170ms/step - loss: 0.0306 - acc: 0.9571 - val_loss: 0.1550 - val_ac
c: 0.7700
Epoch 111/300
1/1 [==============================] - 0s 170ms/step - loss: 0.0270 - acc: 0.9714 - val_loss: 0.1544 - val_ac
c: 0.7640
Epoch 112/300
1/1 [==============================] - 0s 211ms/step - loss: 0.0280 - acc: 0.9714 - val_loss: 0.1531 - val_ac
c: 0.7660
Epoch 113/300
1/1 [==============================] - 0s 194ms/step - loss: 0.0296 - acc: 0.9500 - val_loss: 0.1519 - val_ac
c: 0.7760
Epoch 114/300
1/1 [==============================] - 0s 182ms/step - loss: 0.0272 - acc: 0.9714 - val_loss: 0.1511 - val_ac
c: 0.7820
Epoch 115/300
1/1 [==============================] - 0s 167ms/step - loss: 0.0285 - acc: 0.9857 - val_loss: 0.1492 - val_ac
c: 0.7800
Epoch 116/300
1/1 [==============================] - 0s 167ms/step - loss: 0.0256 - acc: 0.9714 - val_loss: 0.1488 - val_ac
c: 0.7840
Epoch 117/300
1/1 [==============================] - 0s 161ms/step - loss: 0.0267 - acc: 0.9714 - val_loss: 0.1492 - val_ac
c: 0.7800
Epoch 118/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0275 - acc: 0.9643 - val_loss: 0.1486 - val_ac
```

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c: 0.7820
Epoch 119/300
1/1 [==============================] - 0s 176ms/step - loss: 0.0263 - acc: 0.9857 - val_loss: 0.1476 - val_ac
c: 0.7900
Epoch 120/300
1/1 [==============================] - 0s 188ms/step - loss: 0.0291 - acc: 0.9429 - val_loss: 0.1465 - val_ac
c: 0.7900
Epoch 121/300
1/1 [==============================] - 0s 184ms/step - loss: 0.0285 - acc: 0.9786 - val_loss: 0.1444 - val_ac
c: 0.7880
Epoch 122/300
1/1 [==============================] - 0s 227ms/step - loss: 0.0272 - acc: 0.9786 - val_loss: 0.1431 - val_ac
c: 0.7960
Epoch 123/300
1/1 [==============================] - 0s 201ms/step - loss: 0.0275 - acc: 0.9714 - val_loss: 0.1435 - val_ac
c: 0.7980
Epoch 124/300
1/1 [==============================] - 0s 175ms/step - loss: 0.0263 - acc: 0.9714 - val_loss: 0.1444 - val_ac
c: 0.7980
Epoch 125/300
1/1 [==============================] - 0s 165ms/step - loss: 0.0272 - acc: 0.9786 - val_loss: 0.1450 - val_ac
c: 0.7920
Epoch 126/300
1/1 [==============================] - 0s 184ms/step - loss: 0.0288 - acc: 0.9714 - val_loss: 0.1461 - val_ac
c: 0.7880
Epoch 127/300
1/1 [==============================] - 0s 166ms/step - loss: 0.0298 - acc: 0.9643 - val_loss: 0.1482 - val_ac
c: 0.7820
Epoch 128/300
1/1 [==============================] - 0s 180ms/step - loss: 0.0295 - acc: 0.9786 - val_loss: 0.1501 - val_ac
c: 0.7760
Epoch 129/300
1/1 [==============================] - 0s 176ms/step - loss: 0.0270 - acc: 0.9643 - val_loss: 0.1505 - val_ac
c: 0.7680
Epoch 130/300
1/1 [==============================] - 0s 192ms/step - loss: 0.0255 - acc: 0.9786 - val_loss: 0.1507 - val_ac
c: 0.7680
Epoch 131/300
1/1 [==============================] - 0s 188ms/step - loss: 0.0283 - acc: 0.9714 - val_loss: 0.1496 - val_ac
c: 0.7740
Epoch 132/300
1/1 [==============================] - 0s 202ms/step - loss: 0.0269 - acc: 0.9643 - val_loss: 0.1474 - val_ac
c: 0.7760
Epoch 133/300
1/1 [==============================] - 0s 401ms/step - loss: 0.0290 - acc: 0.9571 - val_loss: 0.1446 - val_ac
c: 0.7820
Epoch 134/300
1/1 [==============================] - 0s 217ms/step - loss: 0.0292 - acc: 0.9500 - val_loss: 0.1410 - val_ac
c: 0.7880
Epoch 135/300
1/1 [==============================] - 0s 211ms/step - loss: 0.0247 - acc: 0.9857 - val_loss: 0.1384 - val_ac
c: 0.7920
Epoch 136/300
1/1 [==============================] - 0s 199ms/step - loss: 0.0268 - acc: 0.9929 - val_loss: 0.1382 - val_ac
c: 0.7880
Epoch 137/300
1/1 [==============================] - 0s 247ms/step - loss: 0.0271 - acc: 0.9786 - val_loss: 0.1394 - val_ac
c: 0.7880
Epoch 138/300
1/1 [==============================] - 0s 229ms/step - loss: 0.0257 - acc: 1.0000 - val_loss: 0.1414 - val_ac
c: 0.7820
Epoch 139/300
1/1 [==============================] - 0s 253ms/step - loss: 0.0257 - acc: 0.9857 - val_loss: 0.1445 - val_ac
c: 0.7820
Epoch 140/300
1/1 [==============================] - 0s 247ms/step - loss: 0.0318 - acc: 0.9429 - val_loss: 0.1471 - val_ac
c: 0.7820
Epoch 141/300
1/1 [==============================] - 0s 227ms/step - loss: 0.0237 - acc: 0.9786 - val_loss: 0.1490 - val_ac
c: 0.7840
Epoch 142/300
```

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1/1 [==============================] - 0s 459ms/step - loss: 0.0275 - acc: 0.9714 - val_loss: 0.1496 - val_ac
c: 0.7780
Epoch 143/300
1/1 [==============================] - 0s 253ms/step - loss: 0.0258 - acc: 0.9714 - val_loss: 0.1489 - val_ac
c: 0.7740
Epoch 144/300
1/1 [==============================] - 0s 349ms/step - loss: 0.0244 - acc: 0.9786 - val_loss: 0.1475 - val_ac
c: 0.7740
Epoch 145/300
1/1 [==============================] - 0s 211ms/step - loss: 0.0258 - acc: 0.9714 - val_loss: 0.1453 - val_ac
c: 0.7760
Epoch 146/300
1/1 [==============================] - 0s 232ms/step - loss: 0.0270 - acc: 0.9714 - val_loss: 0.1436 - val_ac
c: 0.7840
Epoch 147/300
1/1 [==============================] - 0s 247ms/step - loss: 0.0258 - acc: 0.9786 - val_loss: 0.1425 - val_ac
c: 0.7820
Epoch 148/300
1/1 [==============================] - 0s 308ms/step - loss: 0.0252 - acc: 0.9571 - val_loss: 0.1411 - val_ac
c: 0.7740
Epoch 149/300
1/1 [==============================] - 0s 269ms/step - loss: 0.0242 - acc: 0.9786 - val_loss: 0.1402 - val_ac
c: 0.7740
Epoch 150/300
1/1 [==============================] - 0s 226ms/step - loss: 0.0255 - acc: 0.9786 - val_loss: 0.1398 - val_ac
c: 0.7840
Epoch 151/300
1/1 [==============================] - 0s 274ms/step - loss: 0.0239 - acc: 0.9857 - val_loss: 0.1407 - val_ac
c: 0.7840
Epoch 152/300
1/1 [==============================] - 0s 241ms/step - loss: 0.0251 - acc: 0.9500 - val_loss: 0.1433 - val_ac
c: 0.7800
Epoch 153/300
1/1 [==============================] - 0s 223ms/step - loss: 0.0264 - acc: 0.9714 - val_loss: 0.1463 - val_ac
c: 0.7740
Epoch 154/300
1/1 [==============================] - 0s 193ms/step - loss: 0.0254 - acc: 0.9643 - val_loss: 0.1469 - val_ac
c: 0.7760
Epoch 155/300
1/1 [==============================] - 0s 224ms/step - loss: 0.0268 - acc: 0.9786 - val_loss: 0.1455 - val_ac
c: 0.7760
Epoch 156/300
1/1 [==============================] - 0s 193ms/step - loss: 0.0253 - acc: 0.9643 - val_loss: 0.1457 - val_ac
c: 0.7740
Epoch 157/300
1/1 [==============================] - 0s 215ms/step - loss: 0.0240 - acc: 0.9714 - val_loss: 0.1469 - val_ac
c: 0.7820
Epoch 158/300
1/1 [==============================] - 0s 235ms/step - loss: 0.0253 - acc: 0.9643 - val_loss: 0.1468 - val_ac
c: 0.7780
Epoch 159/300
1/1 [==============================] - 0s 232ms/step - loss: 0.0261 - acc: 0.9286 - val_loss: 0.1454 - val_ac
c: 0.7720
Epoch 160/300
1/1 [==============================] - 0s 234ms/step - loss: 0.0247 - acc: 0.9786 - val_loss: 0.1438 - val_ac
c: 0.7780
Epoch 161/300
1/1 [==============================] - 0s 219ms/step - loss: 0.0274 - acc: 0.9286 - val_loss: 0.1423 - val_ac
c: 0.7780
Epoch 162/300
1/1 [==============================] - 0s 247ms/step - loss: 0.0278 - acc: 0.9500 - val_loss: 0.1437 - val_ac
c: 0.7800
Epoch 163/300
1/1 [==============================] - 0s 238ms/step - loss: 0.0242 - acc: 0.9714 - val_loss: 0.1457 - val_ac
c: 0.7740
Epoch 164/300
1/1 [==============================] - 0s 236ms/step - loss: 0.0263 - acc: 0.9571 - val_loss: 0.1476 - val_ac
c: 0.7760
Epoch 165/300
1/1 [==============================] - 0s 230ms/step - loss: 0.0255 - acc: 0.9571 - val_loss: 0.1472 - val_ac
c: 0.7860
```

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Epoch 166/300
1/1 [==============================] - 0s 193ms/step - loss: 0.0237 - acc: 0.9786 - val_loss: 0.1463 - val_ac
c: 0.7780
Epoch 167/300
1/1 [==============================] - 0s 181ms/step - loss: 0.0273 - acc: 0.9571 - val_loss: 0.1458 - val_ac
c: 0.7660
Epoch 168/300
1/1 [==============================] - 0s 204ms/step - loss: 0.0224 - acc: 0.9857 - val_loss: 0.1455 - val_ac
c: 0.7660
Epoch 169/300
1/1 [==============================] - 0s 289ms/step - loss: 0.0252 - acc: 0.9714 - val_loss: 0.1461 - val_ac
c: 0.7640
Epoch 170/300
1/1 [==============================] - 0s 236ms/step - loss: 0.0258 - acc: 0.9786 - val_loss: 0.1458 - val_ac
c: 0.7640
Epoch 171/300
1/1 [==============================] - 0s 200ms/step - loss: 0.0229 - acc: 0.9714 - val_loss: 0.1454 - val_ac
c: 0.7660
Epoch 172/300
1/1 [==============================] - 0s 201ms/step - loss: 0.0244 - acc: 0.9786 - val_loss: 0.1449 - val_ac
c: 0.7660
Epoch 173/300
1/1 [==============================] - 0s 215ms/step - loss: 0.0242 - acc: 0.9786 - val_loss: 0.1438 - val_ac
c: 0.7720
Epoch 174/300
1/1 [==============================] - 0s 194ms/step - loss: 0.0230 - acc: 0.9929 - val_loss: 0.1453 - val_ac
c: 0.7780
Epoch 175/300
1/1 [==============================] - 0s 201ms/step - loss: 0.0250 - acc: 0.9786 - val_loss: 0.1454 - val_ac
c: 0.7820
Epoch 176/300
1/1 [==============================] - 0s 254ms/step - loss: 0.0232 - acc: 0.9786 - val_loss: 0.1460 - val_ac
c: 0.7800
Epoch 177/300
1/1 [==============================] - 0s 219ms/step - loss: 0.0248 - acc: 0.9571 - val_loss: 0.1467 - val_ac
c: 0.7620
Epoch 178/300
1/1 [==============================] - 0s 187ms/step - loss: 0.0264 - acc: 0.9429 - val_loss: 0.1468 - val_ac
c: 0.7560
Epoch 179/300
1/1 [==============================] - 0s 177ms/step - loss: 0.0229 - acc: 0.9714 - val_loss: 0.1469 - val_ac
c: 0.7500
Epoch 180/300
1/1 [==============================] - 0s 210ms/step - loss: 0.0230 - acc: 0.9929 - val_loss: 0.1477 - val_ac
c: 0.7460
Epoch 181/300
1/1 [==============================] - 0s 171ms/step - loss: 0.0232 - acc: 0.9857 - val_loss: 0.1456 - val_ac
c: 0.7540
Epoch 182/300
1/1 [==============================] - 0s 206ms/step - loss: 0.0255 - acc: 0.9643 - val_loss: 0.1451 - val_ac
c: 0.7620
Epoch 183/300
1/1 [==============================] - 0s 166ms/step - loss: 0.0239 - acc: 0.9714 - val_loss: 0.1447 - val_ac
c: 0.7660
Epoch 184/300
1/1 [==============================] - 0s 160ms/step - loss: 0.0226 - acc: 0.9643 - val_loss: 0.1450 - val_ac
c: 0.7720
Epoch 185/300
1/1 [==============================] - 0s 164ms/step - loss: 0.0247 - acc: 0.9786 - val_loss: 0.1442 - val_ac
c: 0.7740
Epoch 186/300
1/1 [==============================] - 0s 192ms/step - loss: 0.0233 - acc: 0.9643 - val_loss: 0.1442 - val_ac
c: 0.7740
Epoch 187/300
1/1 [==============================] - 0s 160ms/step - loss: 0.0232 - acc: 0.9786 - val_loss: 0.1448 - val_ac
c: 0.7760
Epoch 188/300
1/1 [==============================] - 0s 179ms/step - loss: 0.0260 - acc: 0.9500 - val_loss: 0.1463 - val_ac
c: 0.7800
Epoch 189/300
1/1 [==============================] - 0s 203ms/step - loss: 0.0238 - acc: 0.9643 - val_loss: 0.1484 - val_ac
```

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c: 0.7700
Epoch 190/300
1/1 [==============================] - 0s 189ms/step - loss: 0.0231 - acc: 0.9714 - val_loss: 0.1506 - val_ac
c: 0.7660
Epoch 191/300
1/1 [==============================] - 0s 183ms/step - loss: 0.0256 - acc: 0.9571 - val_loss: 0.1499 - val_ac
c: 0.7620
Epoch 192/300
1/1 [==============================] - 0s 171ms/step - loss: 0.0244 - acc: 0.9786 - val_loss: 0.1468 - val_ac
c: 0.7720
Epoch 193/300
1/1 [==============================] - 0s 157ms/step - loss: 0.0244 - acc: 0.9786 - val_loss: 0.1441 - val_ac
c: 0.7620
Epoch 194/300
1/1 [==============================] - 0s 159ms/step - loss: 0.0250 - acc: 0.9714 - val_loss: 0.1422 - val_ac
c: 0.7780
Epoch 195/300
1/1 [==============================] - 0s 190ms/step - loss: 0.0242 - acc: 0.9643 - val_loss: 0.1407 - val_ac
c: 0.7780
Epoch 196/300
1/1 [==============================] - 0s 195ms/step - loss: 0.0231 - acc: 0.9643 - val_loss: 0.1398 - val_ac
c: 0.7760
Epoch 197/300
1/1 [==============================] - 0s 200ms/step - loss: 0.0236 - acc: 0.9714 - val_loss: 0.1388 - val_ac
c: 0.7820
Epoch 198/300
1/1 [==============================] - 0s 188ms/step - loss: 0.0211 - acc: 0.9929 - val_loss: 0.1380 - val_ac
c: 0.7760
Epoch 199/300
1/1 [==============================] - 0s 163ms/step - loss: 0.0227 - acc: 0.9786 - val_loss: 0.1378 - val_ac
c: 0.7840
Epoch 200/300
1/1 [==============================] - 0s 185ms/step - loss: 0.0232 - acc: 0.9714 - val_loss: 0.1372 - val_ac
c: 0.7800
Epoch 201/300
1/1 [==============================] - 0s 202ms/step - loss: 0.0235 - acc: 0.9643 - val_loss: 0.1381 - val_ac
c: 0.7860
Epoch 202/300
1/1 [==============================] - 0s 210ms/step - loss: 0.0224 - acc: 0.9786 - val_loss: 0.1391 - val_ac
c: 0.7860
Epoch 203/300
1/1 [==============================] - 0s 194ms/step - loss: 0.0209 - acc: 1.0000 - val_loss: 0.1408 - val_ac
c: 0.7840
Epoch 204/300
1/1 [==============================] - 0s 189ms/step - loss: 0.0250 - acc: 0.9643 - val_loss: 0.1414 - val_ac
c: 0.7740
Epoch 205/300
1/1 [==============================] - 0s 180ms/step - loss: 0.0225 - acc: 0.9857 - val_loss: 0.1409 - val_ac
c: 0.7820
Epoch 206/300
1/1 [==============================] - 0s 171ms/step - loss: 0.0239 - acc: 0.9571 - val_loss: 0.1407 - val_ac
c: 0.7840
Epoch 207/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0216 - acc: 0.9929 - val_loss: 0.1412 - val_ac
c: 0.7860
Epoch 208/300
1/1 [==============================] - 0s 174ms/step - loss: 0.0237 - acc: 0.9786 - val_loss: 0.1426 - val_ac
c: 0.7840
Epoch 209/300
1/1 [==============================] - 0s 164ms/step - loss: 0.0248 - acc: 0.9500 - val_loss: 0.1438 - val_ac
c: 0.7780
Epoch 210/300
1/1 [==============================] - 0s 181ms/step - loss: 0.0233 - acc: 0.9714 - val_loss: 0.1442 - val_ac
c: 0.7780
Epoch 211/300
1/1 [==============================] - 0s 182ms/step - loss: 0.0225 - acc: 0.9786 - val_loss: 0.1444 - val_ac
c: 0.7760
Epoch 212/300
1/1 [==============================] - 0s 191ms/step - loss: 0.0221 - acc: 0.9643 - val_loss: 0.1444 - val_ac
c: 0.7700
Epoch 213/300
```

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1/1 [==============================] - 0s 171ms/step - loss: 0.0230 - acc: 0.9500 - val_loss: 0.1420 - val_ac
c: 0.7740
Epoch 214/300
1/1 [==============================] - 0s 168ms/step - loss: 0.0229 - acc: 0.9786 - val_loss: 0.1402 - val_ac
c: 0.7780
Epoch 215/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0229 - acc: 0.9786 - val_loss: 0.1372 - val_ac
c: 0.7820
Epoch 216/300
1/1 [==============================] - 0s 175ms/step - loss: 0.0217 - acc: 0.9786 - val_loss: 0.1357 - val_ac
c: 0.7860
Epoch 217/300
1/1 [==============================] - 0s 184ms/step - loss: 0.0217 - acc: 0.9714 - val_loss: 0.1370 - val_ac
c: 0.7880
Epoch 218/300
1/1 [==============================] - 0s 170ms/step - loss: 0.0224 - acc: 0.9643 - val_loss: 0.1405 - val_ac
c: 0.7880
Epoch 219/300
1/1 [==============================] - 0s 173ms/step - loss: 0.0217 - acc: 0.9571 - val_loss: 0.1449 - val_ac
c: 0.7800
Epoch 220/300
1/1 [==============================] - 0s 167ms/step - loss: 0.0225 - acc: 0.9786 - val_loss: 0.1449 - val_ac
c: 0.7800
Epoch 221/300
1/1 [==============================] - 0s 202ms/step - loss: 0.0203 - acc: 0.9857 - val_loss: 0.1448 - val_ac
c: 0.7740
Epoch 222/300
1/1 [==============================] - 0s 183ms/step - loss: 0.0236 - acc: 0.9643 - val_loss: 0.1430 - val_ac
c: 0.7740
Epoch 223/300
1/1 [==============================] - 0s 178ms/step - loss: 0.0220 - acc: 0.9786 - val_loss: 0.1401 - val_ac
c: 0.7760
Epoch 224/300
1/1 [==============================] - 0s 191ms/step - loss: 0.0189 - acc: 1.0000 - val_loss: 0.1363 - val_ac
c: 0.7800
Epoch 225/300
1/1 [==============================] - 0s 176ms/step - loss: 0.0206 - acc: 1.0000 - val_loss: 0.1332 - val_ac
c: 0.7940
Epoch 226/300
1/1 [==============================] - 0s 173ms/step - loss: 0.0235 - acc: 0.9714 - val_loss: 0.1331 - val_ac
c: 0.7860
Epoch 227/300
1/1 [==============================] - 0s 177ms/step - loss: 0.0210 - acc: 0.9857 - val_loss: 0.1353 - val_ac
c: 0.7820
Epoch 228/300
1/1 [==============================] - 0s 173ms/step - loss: 0.0207 - acc: 1.0000 - val_loss: 0.1393 - val_ac
c: 0.7840
Epoch 229/300
1/1 [==============================] - 0s 173ms/step - loss: 0.0214 - acc: 0.9929 - val_loss: 0.1420 - val_ac
c: 0.7840
Epoch 230/300
1/1 [==============================] - 0s 173ms/step - loss: 0.0229 - acc: 0.9714 - val_loss: 0.1430 - val_ac
c: 0.7860
Epoch 231/300
1/1 [==============================] - 0s 173ms/step - loss: 0.0213 - acc: 0.9714 - val_loss: 0.1441 - val_ac
c: 0.7920
Epoch 232/300
1/1 [==============================] - 0s 187ms/step - loss: 0.0219 - acc: 0.9786 - val_loss: 0.1423 - val_ac
c: 0.7900
Epoch 233/300
1/1 [==============================] - 0s 178ms/step - loss: 0.0206 - acc: 0.9786 - val_loss: 0.1406 - val_ac
c: 0.7900
Epoch 234/300
1/1 [==============================] - 0s 182ms/step - loss: 0.0196 - acc: 0.9786 - val_loss: 0.1372 - val_ac
c: 0.7920
Epoch 235/300
1/1 [==============================] - 0s 186ms/step - loss: 0.0221 - acc: 0.9714 - val_loss: 0.1362 - val_ac
c: 0.7780
Epoch 236/300
1/1 [==============================] - 0s 205ms/step - loss: 0.0221 - acc: 0.9714 - val_loss: 0.1371 - val_ac
c: 0.7760
```

```
Epoch 237/300
1/1 [==============================] - 0s 170ms/step - loss: 0.0223 - acc: 0.9500 - val_loss: 0.1414 - val_ac
c: 0.7700
Epoch 238/300
1/1 [==============================] - 0s 177ms/step - loss: 0.0231 - acc: 0.9500 - val_loss: 0.1474 - val_ac
c: 0.7620
Epoch 239/300
1/1 [==============================] - 0s 196ms/step - loss: 0.0205 - acc: 0.9643 - val_loss: 0.1513 - val_ac
c: 0.7620
Epoch 240/300
1/1 [==============================] - 0s 198ms/step - loss: 0.0198 - acc: 0.9857 - val_loss: 0.1525 - val_ac
c: 0.7660
Epoch 241/300
1/1 [==============================] - 0s 223ms/step - loss: 0.0214 - acc: 0.9857 - val_loss: 0.1507 - val_ac
c: 0.7660
Epoch 242/300
1/1 [==============================] - 0s 199ms/step - loss: 0.0230 - acc: 0.9714 - val_loss: 0.1472 - val_ac
c: 0.7700
Epoch 243/300
1/1 [==============================] - 0s 195ms/step - loss: 0.0214 - acc: 0.9857 - val_loss: 0.1443 - val_ac
c: 0.7740
Epoch 244/300
1/1 [==============================] - 0s 284ms/step - loss: 0.0231 - acc: 0.9500 - val_loss: 0.1412 - val_ac
c: 0.7740
Epoch 245/300
1/1 [==============================] - 0s 181ms/step - loss: 0.0195 - acc: 0.9786 - val_loss: 0.1395 - val_ac
c: 0.7660
Epoch 246/300
1/1 [==============================] - 0s 179ms/step - loss: 0.0194 - acc: 0.9929 - val_loss: 0.1385 - val_ac
c: 0.7720
Epoch 247/300
1/1 [==============================] - 0s 216ms/step - loss: 0.0233 - acc: 0.9643 - val_loss: 0.1383 - val_ac
c: 0.7740
Epoch 248/300
1/1 [==============================] - 0s 192ms/step - loss: 0.0214 - acc: 0.9857 - val_loss: 0.1379 - val_ac
c: 0.7700
Epoch 249/300
1/1 [==============================] - 0s 172ms/step - loss: 0.0212 - acc: 0.9786 - val_loss: 0.1388 - val_ac
c: 0.7720
Epoch 250/300
1/1 [==============================] - 0s 208ms/step - loss: 0.0218 - acc: 0.9429 - val_loss: 0.1399 - val_ac
c: 0.7760
Epoch 251/300
1/1 [==============================] - 0s 171ms/step - loss: 0.0211 - acc: 0.9714 - val_loss: 0.1400 - val_ac
c: 0.7840
Epoch 252/300
1/1 [==============================] - 0s 171ms/step - loss: 0.0199 - acc: 1.0000 - val_loss: 0.1385 - val_ac
c: 0.7920
Epoch 253/300
1/1 [==============================] - 0s 168ms/step - loss: 0.0207 - acc: 0.9714 - val_loss: 0.1371 - val_ac
c: 0.7860
Epoch 254/300
1/1 [==============================] - 0s 173ms/step - loss: 0.0216 - acc: 0.9786 - val_loss: 0.1371 - val_ac
c: 0.7820
Epoch 255/300
1/1 [==============================] - 0s 185ms/step - loss: 0.0214 - acc: 0.9714 - val_loss: 0.1377 - val_ac
c: 0.7780
Epoch 256/300
1/1 [==============================] - 0s 222ms/step - loss: 0.0233 - acc: 0.9643 - val_loss: 0.1374 - val_ac
c: 0.7760
Epoch 257/300
1/1 [==============================] - 0s 201ms/step - loss: 0.0217 - acc: 0.9857 - val_loss: 0.1368 - val_ac
c: 0.7680
Epoch 258/300
1/1 [==============================] - 0s 194ms/step - loss: 0.0212 - acc: 0.9786 - val_loss: 0.1381 - val_ac
c: 0.7660
Epoch 259/300
1/1 [==============================] - 0s 169ms/step - loss: 0.0203 - acc: 0.9786 - val_loss: 0.1401 - val_ac
c: 0.7680
Epoch 260/300
1/1 [==============================] - 0s 158ms/step - loss: 0.0198 - acc: 1.0000 - val_loss: 0.1424 - val_ac
```

```
c: 0.7640
Epoch 261/300
1/1 [==============================] - 0s 156ms/step - loss: 0.0187 - acc: 1.0000 - val_loss: 0.1443 - val_ac
c: 0.7600
Epoch 262/300
1/1 [==============================] - 0s 160ms/step - loss: 0.0195 - acc: 1.0000 - val_loss: 0.1443 - val_ac
c: 0.7620
Epoch 263/300
1/1 [==============================] - 0s 159ms/step - loss: 0.0208 - acc: 0.9786 - val_loss: 0.1440 - val_ac
c: 0.7660
Epoch 264/300
1/1 [==============================] - 0s 156ms/step - loss: 0.0191 - acc: 1.0000 - val_loss: 0.1438 - val_ac
c: 0.7660
Epoch 265/300
1/1 [==============================] - 0s 160ms/step - loss: 0.0209 - acc: 0.9714 - val_loss: 0.1424 - val_ac
c: 0.7720
Epoch 266/300
1/1 [==============================] - 0s 159ms/step - loss: 0.0195 - acc: 0.9786 - val_loss: 0.1388 - val_ac
c: 0.7780
Epoch 267/300
1/1 [==============================] - 0s 158ms/step - loss: 0.0199 - acc: 0.9857 - val_loss: 0.1356 - val_ac
c: 0.7860
Epoch 268/300
1/1 [==============================] - 0s 160ms/step - loss: 0.0189 - acc: 0.9786 - val_loss: 0.1345 - val_ac
c: 0.7900
Epoch 269/300
1/1 [==============================] - 0s 174ms/step - loss: 0.0201 - acc: 0.9643 - val_loss: 0.1358 - val_ac
c: 0.7860
Epoch 270/300
1/1 [==============================] - 0s 169ms/step - loss: 0.0205 - acc: 0.9929 - val_loss: 0.1379 - val_ac
c: 0.7820
Epoch 271/300
1/1 [==============================] - 0s 167ms/step - loss: 0.0195 - acc: 0.9786 - val_loss: 0.1405 - val_ac
c: 0.7760
Epoch 272/300
1/1 [==============================] - 0s 174ms/step - loss: 0.0194 - acc: 0.9786 - val_loss: 0.1431 - val_ac
c: 0.7640
Epoch 273/300
1/1 [==============================] - 0s 169ms/step - loss: 0.0203 - acc: 0.9714 - val_loss: 0.1439 - val_ac
c: 0.7740
Epoch 274/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0204 - acc: 0.9643 - val_loss: 0.1431 - val_ac
c: 0.7780
Epoch 275/300
1/1 [==============================] - 0s 155ms/step - loss: 0.0186 - acc: 0.9786 - val_loss: 0.1402 - val_ac
c: 0.7820
Epoch 276/300
1/1 [==============================] - 0s 158ms/step - loss: 0.0202 - acc: 0.9857 - val_loss: 0.1364 - val_ac
c: 0.7880
Epoch 277/300
1/1 [==============================] - 0s 176ms/step - loss: 0.0214 - acc: 0.9714 - val_loss: 0.1356 - val_ac
c: 0.7920
Epoch 278/300
1/1 [==============================] - 0s 157ms/step - loss: 0.0192 - acc: 0.9714 - val_loss: 0.1365 - val_ac
c: 0.7920
Epoch 279/300
1/1 [==============================] - 0s 156ms/step - loss: 0.0220 - acc: 0.9643 - val_loss: 0.1394 - val_ac
c: 0.7880
Epoch 280/300
1/1 [==============================] - 0s 158ms/step - loss: 0.0184 - acc: 0.9857 - val_loss: 0.1431 - val_ac
c: 0.7840
Epoch 281/300
1/1 [==============================] - 0s 158ms/step - loss: 0.0196 - acc: 0.9786 - val_loss: 0.1480 - val_ac
c: 0.7700
Epoch 282/300
1/1 [==============================] - 0s 163ms/step - loss: 0.0203 - acc: 0.9571 - val_loss: 0.1510 - val_ac
c: 0.7620
Epoch 283/300
1/1 [==============================] - 0s 166ms/step - loss: 0.0215 - acc: 0.9786 - val_loss: 0.1511 - val_ac
c: 0.7660
Epoch 284/300
```

```
1/1 [==============================] - 0s 158ms/step - loss: 0.0227 - acc: 0.9714 - val_loss: 0.1474 - val_ac
c: 0.7640
Epoch 285/300
1/1 [==============================] - 0s 158ms/step - loss: 0.0218 - acc: 0.9643 - val_loss: 0.1419 - val_ac
c: 0.7680
Epoch 286/300
1/1 [==============================] - 0s 155ms/step - loss: 0.0216 - acc: 0.9571 - val_loss: 0.1375 - val_ac
c: 0.7720
Epoch 287/300
1/1 [==============================] - 0s 157ms/step - loss: 0.0199 - acc: 0.9786 - val_loss: 0.1348 - val_ac
c: 0.7760
Epoch 288/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0248 - acc: 0.9500 - val_loss: 0.1358 - val_ac
c: 0.7800
Epoch 289/300
1/1 [==============================] - 0s 155ms/step - loss: 0.0191 - acc: 0.9857 - val_loss: 0.1395 - val_ac
c: 0.7780
Epoch 290/300
1/1 [==============================] - 0s 161ms/step - loss: 0.0204 - acc: 0.9643 - val_loss: 0.1463 - val_ac
c: 0.7680
Epoch 291/300
1/1 [==============================] - 0s 157ms/step - loss: 0.0223 - acc: 0.9571 - val_loss: 0.1542 - val_ac
c: 0.7460
Epoch 292/300
1/1 [==============================] - 0s 160ms/step - loss: 0.0195 - acc: 0.9857 - val_loss: 0.1583 - val_ac
c: 0.7420
Epoch 293/300
1/1 [==============================] - 0s 168ms/step - loss: 0.0237 - acc: 0.9571 - val_loss: 0.1586 - val_ac
c: 0.7440
Epoch 294/300
1/1 [==============================] - 0s 170ms/step - loss: 0.0205 - acc: 0.9714 - val_loss: 0.1533 - val_ac
c: 0.7580
Epoch 295/300
1/1 [==============================] - 0s 171ms/step - loss: 0.0197 - acc: 0.9929 - val_loss: 0.1473 - val_ac
c: 0.7660
Epoch 296/300
1/1 [==============================] - 0s 173ms/step - loss: 0.0210 - acc: 1.0000 - val_loss: 0.1410 - val_ac
c: 0.7760
Epoch 297/300
1/1 [==============================] - 0s 173ms/step - loss: 0.0196 - acc: 0.9929 - val_loss: 0.1362 - val_ac
c: 0.7820
Epoch 298/300
1/1 [==============================] - 0s 158ms/step - loss: 0.0219 - acc: 0.9714 - val_loss: 0.1345 - val_ac
c: 0.7780
Epoch 299/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0228 - acc: 0.9714 - val_loss: 0.1359 - val_ac
c: 0.7720
Epoch 300/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0218 - acc: 0.9714 - val_loss: 0.1390 - val_ac
c: 0.7640
```

Out[ ]: <tensorflow.python.keras.callbacks.History at 0x20585267308>

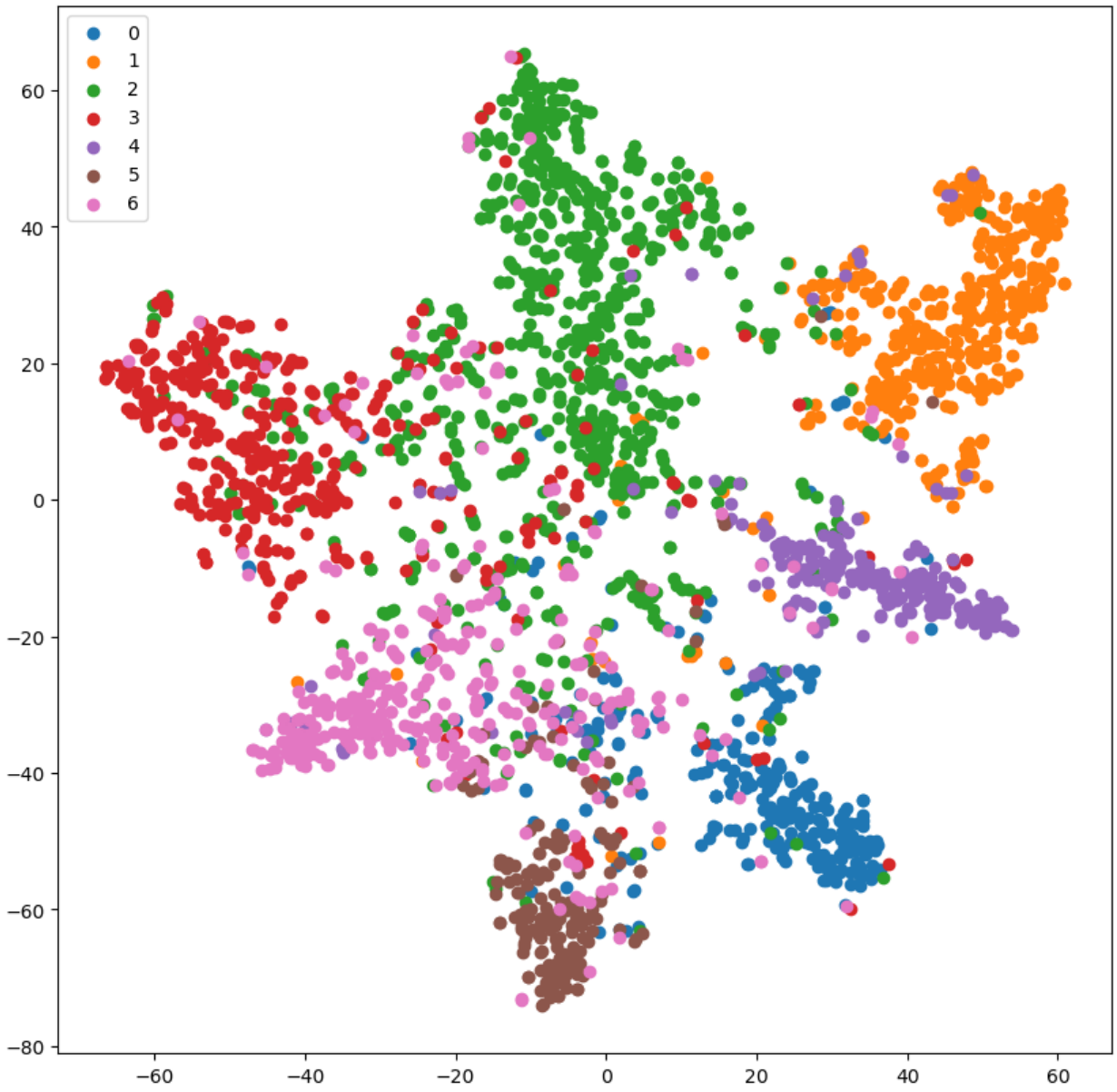
In [ ]:
```
# Evaluate model
X_te = X[test_mask]
A_te = A[test_mask,:][:,test_mask]
y_te = labels_encoded[test_mask]

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       0.80      0.69      0.74       114
    Genetic_Algorithms       0.86      0.87      0.86       156
       Neural_Networks       0.79      0.70      0.74       290
 Probabilistic_Methods       0.76      0.71      0.73       172
Reinforcement_Learning       0.63      0.80      0.70        85
         Rule_Learning       0.52      0.88      0.66        60
                Theory       0.57      0.54      0.56       123

              accuracy                           0.73      1000
             macro avg       0.70      0.74      0.71      1000
          weighted avg       0.74      0.73      0.73      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 = 150
optimizer = Adam(lr=1e-2)
l2_reg = 5e-4
epochs = 300

#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 1/300
1/1 [==============================] - 0s 244ms/step - loss: 0.2190 - acc: 0.1143 - val_loss: 0.4341 - val_ac
c: 0.2740
Epoch 2/300
1/1 [==============================] - ETA: 0s - loss: 0.1741 - acc: 0.3357WARNING:tensorflow:Method (on_trai
n_batch_end) is slow compared to the batch update (0.156036). Check your callbacks.
1/1 [==============================] - 0s 225ms/step - loss: 0.1741 - acc: 0.3357 - val_loss: 0.3971 - val_ac
c: 0.3960
Epoch 3/300
1/1 [==============================] - 0s 206ms/step - loss: 0.1400 - acc: 0.5143 - val_loss: 0.3649 - val_ac
c: 0.4840
Epoch 4/300
1/1 [==============================] - 0s 166ms/step - loss: 0.1108 - acc: 0.6786 - val_loss: 0.3318 - val_ac
c: 0.5440
Epoch 5/300
1/1 [==============================] - 0s 167ms/step - loss: 0.0873 - acc: 0.7571 - val_loss: 0.3002 - val_ac
c: 0.5800
Epoch 6/300
1/1 [==============================] - 0s 163ms/step - loss: 0.0665 - acc: 0.8286 - val_loss: 0.2746 - val_ac
c: 0.5720
Epoch 7/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0528 - acc: 0.9000 - val_loss: 0.2741 - val_ac
c: 0.5540
Epoch 8/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0458 - acc: 0.9429 - val_loss: 0.2830 - val_ac
c: 0.5360
Epoch 9/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0454 - acc: 0.9500 - val_loss: 0.2994 - val_ac
c: 0.5520
Epoch 10/300
1/1 [==============================] - 0s 192ms/step - loss: 0.0418 - acc: 0.9929 - val_loss: 0.3210 - val_ac
c: 0.5540
Epoch 11/300
1/1 [==============================] - 0s 191ms/step - loss: 0.0445 - acc: 0.9500 - val_loss: 0.3357 - val_ac
c: 0.5580
Epoch 12/300
1/1 [==============================] - 0s 202ms/step - loss: 0.0410 - acc: 0.9929 - val_loss: 0.3490 - val_ac
c: 0.5460
Epoch 13/300
1/1 [==============================] - 0s 281ms/step - loss: 0.0408 - acc: 0.9857 - val_loss: 0.3628 - val_ac
c: 0.5560
Epoch 14/300
1/1 [==============================] - 0s 236ms/step - loss: 0.0388 - acc: 1.0000 - val_loss: 0.3613 - val_ac
c: 0.5520
Epoch 15/300
1/1 [==============================] - 0s 255ms/step - loss: 0.0366 - acc: 0.9929 - val_loss: 0.3517 - val_ac
c: 0.5840
Epoch 16/300
1/1 [==============================] - 0s 367ms/step - loss: 0.0353 - acc: 0.9857 - val_loss: 0.3508 - val_ac
c: 0.5860
Epoch 17/300
1/1 [==============================] - 0s 301ms/step - loss: 0.0318 - acc: 0.9857 - val_loss: 0.3657 - val_ac
c: 0.5740
Epoch 18/300
1/1 [==============================] - 0s 269ms/step - loss: 0.0288 - acc: 0.9929 - val_loss: 0.3964 - val_ac
c: 0.5320
Epoch 19/300
1/1 [==============================] - 0s 252ms/step - loss: 0.0259 - acc: 1.0000 - val_loss: 0.4228 - val_ac
c: 0.5200
Epoch 20/300
1/1 [==============================] - 0s 278ms/step - loss: 0.0240 - acc: 1.0000 - val_loss: 0.4413 - val_ac
c: 0.5060
Epoch 21/300
1/1 [==============================] - 0s 373ms/step - loss: 0.0244 - acc: 0.9786 - val_loss: 0.4186 - val_ac
c: 0.5080
Epoch 22/300
1/1 [==============================] - 0s 300ms/step - loss: 0.0241 - acc: 0.9714 - val_loss: 0.4026 - val_ac
c: 0.5340
Epoch 23/300
1/1 [==============================] - 0s 242ms/step - loss: 0.0220 - acc: 0.9714 - val_loss: 0.3840 - val_ac
c: 0.5500
```

```
Epoch 24/300
1/1 [==============================] - 0s 344ms/step - loss: 0.0216 - acc: 0.9786 - val_loss: 0.3680 - val_ac
c: 0.5540
Epoch 25/300
1/1 [==============================] - 0s 229ms/step - loss: 0.0239 - acc: 0.9571 - val_loss: 0.3533 - val_ac
c: 0.5380
Epoch 26/300
1/1 [==============================] - 0s 241ms/step - loss: 0.0189 - acc: 0.9929 - val_loss: 0.3533 - val_ac
c: 0.5280
Epoch 27/300
1/1 [==============================] - 0s 310ms/step - loss: 0.0214 - acc: 0.9714 - val_loss: 0.3637 - val_ac
c: 0.5020
Epoch 28/300
1/1 [==============================] - 0s 262ms/step - loss: 0.0201 - acc: 0.9857 - val_loss: 0.3750 - val_ac
c: 0.4960
Epoch 29/300
1/1 [==============================] - 0s 242ms/step - loss: 0.0207 - acc: 0.9714 - val_loss: 0.3759 - val_ac
c: 0.4980
Epoch 30/300
1/1 [==============================] - 0s 253ms/step - loss: 0.0211 - acc: 0.9786 - val_loss: 0.3725 - val_ac
c: 0.5060
Epoch 31/300
1/1 [==============================] - 0s 274ms/step - loss: 0.0217 - acc: 0.9786 - val_loss: 0.3606 - val_ac
c: 0.5120
Epoch 32/300
1/1 [==============================] - 0s 249ms/step - loss: 0.0196 - acc: 1.0000 - val_loss: 0.3559 - val_ac
c: 0.5180
Epoch 33/300
1/1 [==============================] - 0s 238ms/step - loss: 0.0207 - acc: 0.9929 - val_loss: 0.3544 - val_ac
c: 0.5260
Epoch 34/300
1/1 [==============================] - 0s 256ms/step - loss: 0.0222 - acc: 0.9857 - val_loss: 0.3493 - val_ac
c: 0.5260
Epoch 35/300
1/1 [==============================] - 0s 226ms/step - loss: 0.0216 - acc: 0.9929 - val_loss: 0.3482 - val_ac
c: 0.5300
Epoch 36/300
1/1 [==============================] - 0s 232ms/step - loss: 0.0222 - acc: 0.9857 - val_loss: 0.3464 - val_ac
c: 0.5280
Epoch 37/300
1/1 [==============================] - 0s 278ms/step - loss: 0.0236 - acc: 0.9786 - val_loss: 0.3361 - val_ac
c: 0.5560
Epoch 38/300
1/1 [==============================] - 0s 281ms/step - loss: 0.0223 - acc: 0.9929 - val_loss: 0.3296 - val_ac
c: 0.5560
Epoch 39/300
1/1 [==============================] - 0s 238ms/step - loss: 0.0219 - acc: 0.9857 - val_loss: 0.3266 - val_ac
c: 0.5500
Epoch 40/300
1/1 [==============================] - 0s 232ms/step - loss: 0.0228 - acc: 0.9857 - val_loss: 0.3223 - val_ac
c: 0.5600
Epoch 41/300
1/1 [==============================] - 0s 264ms/step - loss: 0.0221 - acc: 0.9857 - val_loss: 0.3279 - val_ac
c: 0.5540
Epoch 42/300
1/1 [==============================] - 0s 242ms/step - loss: 0.0212 - acc: 1.0000 - val_loss: 0.3366 - val_ac
c: 0.5460
Epoch 43/300
1/1 [==============================] - 0s 244ms/step - loss: 0.0209 - acc: 1.0000 - val_loss: 0.3472 - val_ac
c: 0.5340
Epoch 44/300
1/1 [==============================] - 0s 244ms/step - loss: 0.0219 - acc: 0.9857 - val_loss: 0.3491 - val_ac
c: 0.5300
Epoch 45/300
1/1 [==============================] - 0s 189ms/step - loss: 0.0204 - acc: 0.9929 - val_loss: 0.3551 - val_ac
c: 0.5200
Epoch 46/300
1/1 [==============================] - 0s 173ms/step - loss: 0.0201 - acc: 0.9929 - val_loss: 0.3588 - val_ac
c: 0.5180
Epoch 47/300
1/1 [==============================] - 0s 219ms/step - loss: 0.0211 - acc: 0.9857 - val_loss: 0.3594 - val_ac
```

```
c: 0.5140
Epoch 48/300
1/1 [==============================] - 0s 199ms/step - loss: 0.0190 - acc: 1.0000 - val_loss: 0.3597 - val_ac
c: 0.5220
Epoch 49/300
1/1 [==============================] - 0s 187ms/step - loss: 0.0189 - acc: 0.9929 - val_loss: 0.3621 - val_ac
c: 0.5200
Epoch 50/300
1/1 [==============================] - 0s 172ms/step - loss: 0.0194 - acc: 0.9929 - val_loss: 0.3711 - val_ac
c: 0.5160
Epoch 51/300
1/1 [==============================] - 0s 163ms/step - loss: 0.0198 - acc: 0.9857 - val_loss: 0.3748 - val_ac
c: 0.4980
Epoch 52/300
1/1 [==============================] - 0s 161ms/step - loss: 0.0174 - acc: 0.9929 - val_loss: 0.3757 - val_ac
c: 0.4960
Epoch 53/300
1/1 [==============================] - 0s 191ms/step - loss: 0.0182 - acc: 0.9929 - val_loss: 0.3798 - val_ac
c: 0.4940
Epoch 54/300
1/1 [==============================] - 0s 156ms/step - loss: 0.0176 - acc: 0.9929 - val_loss: 0.3731 - val_ac
c: 0.4900
Epoch 55/300
1/1 [==============================] - 0s 152ms/step - loss: 0.0180 - acc: 0.9857 - val_loss: 0.3665 - val_ac
c: 0.4940
Epoch 56/300
1/1 [==============================] - 0s 156ms/step - loss: 0.0182 - acc: 0.9786 - val_loss: 0.3572 - val_ac
c: 0.5000
Epoch 57/300
1/1 [==============================] - 0s 156ms/step - loss: 0.0172 - acc: 0.9857 - val_loss: 0.3361 - val_ac
c: 0.5240
Epoch 58/300
1/1 [==============================] - 0s 190ms/step - loss: 0.0169 - acc: 1.0000 - val_loss: 0.3208 - val_ac
c: 0.5380
Epoch 59/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0167 - acc: 0.9929 - val_loss: 0.3163 - val_ac
c: 0.5460
Epoch 60/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0187 - acc: 0.9786 - val_loss: 0.3143 - val_ac
c: 0.5640
Epoch 61/300
1/1 [==============================] - 0s 164ms/step - loss: 0.0172 - acc: 0.9857 - val_loss: 0.3137 - val_ac
c: 0.5660
Epoch 62/300
1/1 [==============================] - 0s 161ms/step - loss: 0.0175 - acc: 0.9857 - val_loss: 0.3210 - val_ac
c: 0.5660
Epoch 63/300
1/1 [==============================] - 0s 174ms/step - loss: 0.0170 - acc: 0.9929 - val_loss: 0.3328 - val_ac
c: 0.5680
Epoch 64/300
1/1 [==============================] - 0s 163ms/step - loss: 0.0192 - acc: 0.9857 - val_loss: 0.3440 - val_ac
c: 0.5680
Epoch 65/300
1/1 [==============================] - 0s 161ms/step - loss: 0.0191 - acc: 0.9714 - val_loss: 0.3601 - val_ac
c: 0.5560
Epoch 66/300
1/1 [==============================] - 0s 160ms/step - loss: 0.0183 - acc: 0.9929 - val_loss: 0.3745 - val_ac
c: 0.5360
Epoch 67/300
1/1 [==============================] - 0s 231ms/step - loss: 0.0188 - acc: 0.9929 - val_loss: 0.3867 - val_ac
c: 0.5060
Epoch 68/300
1/1 [==============================] - 0s 237ms/step - loss: 0.0190 - acc: 0.9929 - val_loss: 0.4084 - val_ac
c: 0.4860
Epoch 69/300
1/1 [==============================] - 0s 197ms/step - loss: 0.0188 - acc: 0.9857 - val_loss: 0.4410 - val_ac
c: 0.4640
Epoch 70/300
1/1 [==============================] - 0s 178ms/step - loss: 0.0239 - acc: 0.9643 - val_loss: 0.4616 - val_ac
c: 0.4520
Epoch 71/300
```

```
1/1 [==============================] - 0s 195ms/step - loss: 0.0205 - acc: 0.9929 - val_loss: 0.4718 - val_ac
c: 0.4600
Epoch 72/300
1/1 [==============================] - 0s 201ms/step - loss: 0.0196 - acc: 0.9857 - val_loss: 0.4800 - val_ac
c: 0.4520
Epoch 73/300
1/1 [==============================] - 0s 191ms/step - loss: 0.0212 - acc: 0.9786 - val_loss: 0.4859 - val_ac
c: 0.4560
Epoch 74/300
1/1 [==============================] - 0s 220ms/step - loss: 0.0225 - acc: 0.9786 - val_loss: 0.4751 - val_ac
c: 0.4580
Epoch 75/300
1/1 [==============================] - 0s 210ms/step - loss: 0.0216 - acc: 0.9857 - val_loss: 0.4468 - val_ac
c: 0.4800
Epoch 76/300
1/1 [==============================] - 0s 161ms/step - loss: 0.0271 - acc: 0.9500 - val_loss: 0.4306 - val_ac
c: 0.4760
Epoch 77/300
1/1 [==============================] - 0s 161ms/step - loss: 0.0224 - acc: 0.9929 - val_loss: 0.4241 - val_ac
c: 0.5020
Epoch 78/300
1/1 [==============================] - 0s 307ms/step - loss: 0.0223 - acc: 0.9929 - val_loss: 0.4297 - val_ac
c: 0.4800
Epoch 79/300
1/1 [==============================] - 0s 311ms/step - loss: 0.0233 - acc: 0.9929 - val_loss: 0.4340 - val_ac
c: 0.4720
Epoch 80/300
1/1 [==============================] - 0s 210ms/step - loss: 0.0248 - acc: 0.9714 - val_loss: 0.4232 - val_ac
c: 0.4700
Epoch 81/300
1/1 [==============================] - 0s 216ms/step - loss: 0.0292 - acc: 0.9571 - val_loss: 0.3845 - val_ac
c: 0.5140
Epoch 82/300
1/1 [==============================] - 0s 286ms/step - loss: 0.0265 - acc: 0.9571 - val_loss: 0.3692 - val_ac
c: 0.5280
Epoch 83/300
1/1 [==============================] - 0s 193ms/step - loss: 0.0287 - acc: 0.9714 - val_loss: 0.3770 - val_ac
c: 0.5220
Epoch 84/300
1/1 [==============================] - 0s 197ms/step - loss: 0.0257 - acc: 0.9857 - val_loss: 0.3976 - val_ac
c: 0.5040
Epoch 85/300
1/1 [==============================] - 0s 209ms/step - loss: 0.0278 - acc: 0.9714 - val_loss: 0.4135 - val_ac
c: 0.5000
Epoch 86/300
1/1 [==============================] - 0s 209ms/step - loss: 0.0293 - acc: 0.9857 - val_loss: 0.4185 - val_ac
c: 0.5060
Epoch 87/300
1/1 [==============================] - 0s 193ms/step - loss: 0.0275 - acc: 0.9857 - val_loss: 0.4178 - val_ac
c: 0.5040
Epoch 88/300
1/1 [==============================] - 0s 171ms/step - loss: 0.0316 - acc: 0.9643 - val_loss: 0.4021 - val_ac
c: 0.5180
Epoch 89/300
1/1 [==============================] - 0s 224ms/step - loss: 0.0304 - acc: 0.9571 - val_loss: 0.4013 - val_ac
c: 0.5180
Epoch 90/300
1/1 [==============================] - 0s 214ms/step - loss: 0.0274 - acc: 1.0000 - val_loss: 0.4091 - val_ac
c: 0.5040
Epoch 91/300
1/1 [==============================] - 0s 213ms/step - loss: 0.0284 - acc: 0.9929 - val_loss: 0.4169 - val_ac
c: 0.5060
Epoch 92/300
1/1 [==============================] - 0s 219ms/step - loss: 0.0299 - acc: 0.9643 - val_loss: 0.4170 - val_ac
c: 0.5180
Epoch 93/300
1/1 [==============================] - 0s 180ms/step - loss: 0.0287 - acc: 0.9929 - val_loss: 0.4149 - val_ac
c: 0.5240
Epoch 94/300
1/1 [==============================] - 0s 206ms/step - loss: 0.0336 - acc: 0.9786 - val_loss: 0.3969 - val_ac
c: 0.5360
```

```
Epoch 95/300
1/1 [==============================] - 0s 210ms/step - loss: 0.0307 - acc: 0.9714 - val_loss: 0.3773 - val_ac
c: 0.5320
Epoch 96/300
1/1 [==============================] - 0s 225ms/step - loss: 0.0307 - acc: 0.9786 - val_loss: 0.3717 - val_ac
c: 0.5340
Epoch 97/300
1/1 [==============================] - 0s 185ms/step - loss: 0.0292 - acc: 0.9857 - val_loss: 0.3790 - val_ac
c: 0.5360
Epoch 98/300
1/1 [==============================] - 0s 179ms/step - loss: 0.0287 - acc: 0.9929 - val_loss: 0.3855 - val_ac
c: 0.5380
Epoch 99/300
1/1 [==============================] - 0s 181ms/step - loss: 0.0310 - acc: 0.9786 - val_loss: 0.3907 - val_ac
c: 0.5280
Epoch 100/300
1/1 [==============================] - 0s 193ms/step - loss: 0.0279 - acc: 0.9929 - val_loss: 0.4030 - val_ac
c: 0.5220
Epoch 101/300
1/1 [==============================] - 0s 198ms/step - loss: 0.0345 - acc: 0.9714 - val_loss: 0.4063 - val_ac
c: 0.5220
Epoch 102/300
1/1 [==============================] - 0s 179ms/step - loss: 0.0296 - acc: 0.9786 - val_loss: 0.4016 - val_ac
c: 0.5160
Epoch 103/300
1/1 [==============================] - 0s 192ms/step - loss: 0.0289 - acc: 0.9857 - val_loss: 0.3990 - val_ac
c: 0.5200
Epoch 104/300
1/1 [==============================] - 0s 187ms/step - loss: 0.0296 - acc: 0.9714 - val_loss: 0.4033 - val_ac
c: 0.5160
Epoch 105/300
1/1 [==============================] - 0s 171ms/step - loss: 0.0340 - acc: 0.9643 - val_loss: 0.4099 - val_ac
c: 0.5060
Epoch 106/300
1/1 [==============================] - 0s 180ms/step - loss: 0.0304 - acc: 0.9714 - val_loss: 0.4108 - val_ac
c: 0.5060
Epoch 107/300
1/1 [==============================] - 0s 186ms/step - loss: 0.0305 - acc: 0.9714 - val_loss: 0.3969 - val_ac
c: 0.5060
Epoch 108/300
1/1 [==============================] - 0s 199ms/step - loss: 0.0327 - acc: 0.9714 - val_loss: 0.3772 - val_ac
c: 0.5340
Epoch 109/300
1/1 [==============================] - 0s 185ms/step - loss: 0.0291 - acc: 0.9929 - val_loss: 0.3757 - val_ac
c: 0.5520
Epoch 110/300
1/1 [==============================] - 0s 179ms/step - loss: 0.0319 - acc: 0.9714 - val_loss: 0.3799 - val_ac
c: 0.5620
Epoch 111/300
1/1 [==============================] - 0s 159ms/step - loss: 0.0316 - acc: 0.9714 - val_loss: 0.3873 - val_ac
c: 0.5620
Epoch 112/300
1/1 [==============================] - 0s 161ms/step - loss: 0.0319 - acc: 0.9714 - val_loss: 0.3892 - val_ac
c: 0.5440
Epoch 113/300
1/1 [==============================] - 0s 190ms/step - loss: 0.0296 - acc: 0.9929 - val_loss: 0.3898 - val_ac
c: 0.5440
Epoch 114/300
1/1 [==============================] - 0s 178ms/step - loss: 0.0342 - acc: 0.9643 - val_loss: 0.3896 - val_ac
c: 0.5420
Epoch 115/300
1/1 [==============================] - 0s 211ms/step - loss: 0.0313 - acc: 0.9786 - val_loss: 0.3927 - val_ac
c: 0.5300
Epoch 116/300
1/1 [==============================] - 0s 167ms/step - loss: 0.0316 - acc: 0.9857 - val_loss: 0.4012 - val_ac
c: 0.5180
Epoch 117/300
1/1 [==============================] - 0s 204ms/step - loss: 0.0330 - acc: 0.9714 - val_loss: 0.4090 - val_ac
c: 0.5080
Epoch 118/300
1/1 [==============================] - 0s 173ms/step - loss: 0.0321 - acc: 0.9929 - val_loss: 0.4104 - val_ac
```

```
c: 0.5020
Epoch 119/300
1/1 [==============================] - 0s 200ms/step - loss: 0.0355 - acc: 0.9714 - val_loss: 0.3993 - val_ac
c: 0.5080
Epoch 120/300
1/1 [==============================] - 0s 205ms/step - loss: 0.0357 - acc: 0.9714 - val_loss: 0.3894 - val_ac
c: 0.5220
Epoch 121/300
1/1 [==============================] - 0s 188ms/step - loss: 0.0332 - acc: 0.9714 - val_loss: 0.3838 - val_ac
c: 0.5180
Epoch 122/300
1/1 [==============================] - 0s 172ms/step - loss: 0.0326 - acc: 0.9857 - val_loss: 0.3814 - val_ac
c: 0.5160
Epoch 123/300
1/1 [==============================] - 0s 157ms/step - loss: 0.0373 - acc: 0.9500 - val_loss: 0.3771 - val_ac
c: 0.5240
Epoch 124/300
1/1 [==============================] - 0s 227ms/step - loss: 0.0336 - acc: 0.9643 - val_loss: 0.3809 - val_ac
c: 0.5340
Epoch 125/300
1/1 [==============================] - 0s 186ms/step - loss: 0.0321 - acc: 0.9929 - val_loss: 0.3886 - val_ac
c: 0.5280
Epoch 126/300
1/1 [==============================] - 0s 248ms/step - loss: 0.0339 - acc: 0.9857 - val_loss: 0.3954 - val_ac
c: 0.5200
Epoch 127/300
1/1 [==============================] - 0s 293ms/step - loss: 0.0343 - acc: 0.9857 - val_loss: 0.4048 - val_ac
c: 0.5220
Epoch 128/300
1/1 [==============================] - 0s 176ms/step - loss: 0.0378 - acc: 0.9643 - val_loss: 0.4082 - val_ac
c: 0.5040
Epoch 129/300
1/1 [==============================] - 0s 165ms/step - loss: 0.0337 - acc: 0.9929 - val_loss: 0.4171 - val_ac
c: 0.4940
Epoch 130/300
1/1 [==============================] - 0s 172ms/step - loss: 0.0367 - acc: 0.9571 - val_loss: 0.4209 - val_ac
c: 0.4940
Epoch 131/300
1/1 [==============================] - 0s 156ms/step - loss: 0.0341 - acc: 0.9857 - val_loss: 0.4254 - val_ac
c: 0.4900
Epoch 132/300
1/1 [==============================] - 0s 160ms/step - loss: 0.0369 - acc: 0.9643 - val_loss: 0.4173 - val_ac
c: 0.4980
Epoch 133/300
1/1 [==============================] - 0s 182ms/step - loss: 0.0365 - acc: 0.9714 - val_loss: 0.4119 - val_ac
c: 0.5000
Epoch 134/300
1/1 [==============================] - 0s 163ms/step - loss: 0.0328 - acc: 0.9857 - val_loss: 0.4117 - val_ac
c: 0.4940
Epoch 135/300
1/1 [==============================] - 0s 151ms/step - loss: 0.0379 - acc: 0.9714 - val_loss: 0.4040 - val_ac
c: 0.5020
Epoch 136/300
1/1 [==============================] - 0s 180ms/step - loss: 0.0364 - acc: 0.9714 - val_loss: 0.4025 - val_ac
c: 0.5040
Epoch 137/300
1/1 [==============================] - 0s 181ms/step - loss: 0.0355 - acc: 0.9857 - val_loss: 0.4059 - val_ac
c: 0.4960
Epoch 138/300
1/1 [==============================] - 0s 168ms/step - loss: 0.0333 - acc: 0.9929 - val_loss: 0.4154 - val_ac
c: 0.4980
Epoch 139/300
1/1 [==============================] - 0s 163ms/step - loss: 0.0344 - acc: 0.9857 - val_loss: 0.4238 - val_ac
c: 0.4960
Epoch 140/300
1/1 [==============================] - 0s 156ms/step - loss: 0.0350 - acc: 0.9857 - val_loss: 0.4283 - val_ac
c: 0.4900
Epoch 141/300
1/1 [==============================] - 0s 157ms/step - loss: 0.0346 - acc: 0.9857 - val_loss: 0.4376 - val_ac
c: 0.4940
Epoch 142/300
```

```
1/1 [==============================] - 0s 153ms/step - loss: 0.0344 - acc: 0.9857 - val_loss: 0.4446 - val_ac
c: 0.4860
Epoch 143/300
1/1 [==============================] - 0s 180ms/step - loss: 0.0335 - acc: 0.9786 - val_loss: 0.4469 - val_ac
c: 0.4860
Epoch 144/300
1/1 [==============================] - 0s 378ms/step - loss: 0.0352 - acc: 0.9786 - val_loss: 0.4419 - val_ac
c: 0.4880
Epoch 145/300
1/1 [==============================] - 0s 224ms/step - loss: 0.0333 - acc: 0.9929 - val_loss: 0.4399 - val_ac
c: 0.4840
Epoch 146/300
1/1 [==============================] - 0s 300ms/step - loss: 0.0361 - acc: 0.9786 - val_loss: 0.4413 - val_ac
c: 0.4860
Epoch 147/300
1/1 [==============================] - 0s 225ms/step - loss: 0.0328 - acc: 0.9786 - val_loss: 0.4377 - val_ac
c: 0.4840
Epoch 148/300
1/1 [==============================] - 0s 185ms/step - loss: 0.0317 - acc: 0.9857 - val_loss: 0.4329 - val_ac
c: 0.4720
Epoch 149/300
1/1 [==============================] - 0s 168ms/step - loss: 0.0323 - acc: 0.9857 - val_loss: 0.4172 - val_ac
c: 0.4840
Epoch 150/300
1/1 [==============================] - 0s 239ms/step - loss: 0.0334 - acc: 0.9857 - val_loss: 0.4040 - val_ac
c: 0.4980
Epoch 151/300
1/1 [==============================] - 0s 153ms/step - loss: 0.0351 - acc: 0.9714 - val_loss: 0.3921 - val_ac
c: 0.5020
Epoch 152/300
1/1 [==============================] - 0s 149ms/step - loss: 0.0349 - acc: 0.9714 - val_loss: 0.3919 - val_ac
c: 0.4920
Epoch 153/300
1/1 [==============================] - 0s 144ms/step - loss: 0.0328 - acc: 0.9857 - val_loss: 0.3887 - val_ac
c: 0.4980
Epoch 154/300
1/1 [==============================] - 0s 145ms/step - loss: 0.0334 - acc: 0.9714 - val_loss: 0.3843 - val_ac
c: 0.4920
Epoch 155/300
1/1 [==============================] - 0s 149ms/step - loss: 0.0344 - acc: 0.9857 - val_loss: 0.3842 - val_ac
c: 0.4940
Epoch 156/300
1/1 [==============================] - 0s 145ms/step - loss: 0.0386 - acc: 0.9571 - val_loss: 0.3795 - val_ac
c: 0.4980
Epoch 157/300
1/1 [==============================] - 0s 162ms/step - loss: 0.0329 - acc: 0.9857 - val_loss: 0.3790 - val_ac
c: 0.4960
```

Out[ ]: <tensorflow.python.keras.callbacks.History at 0x205928e1508>

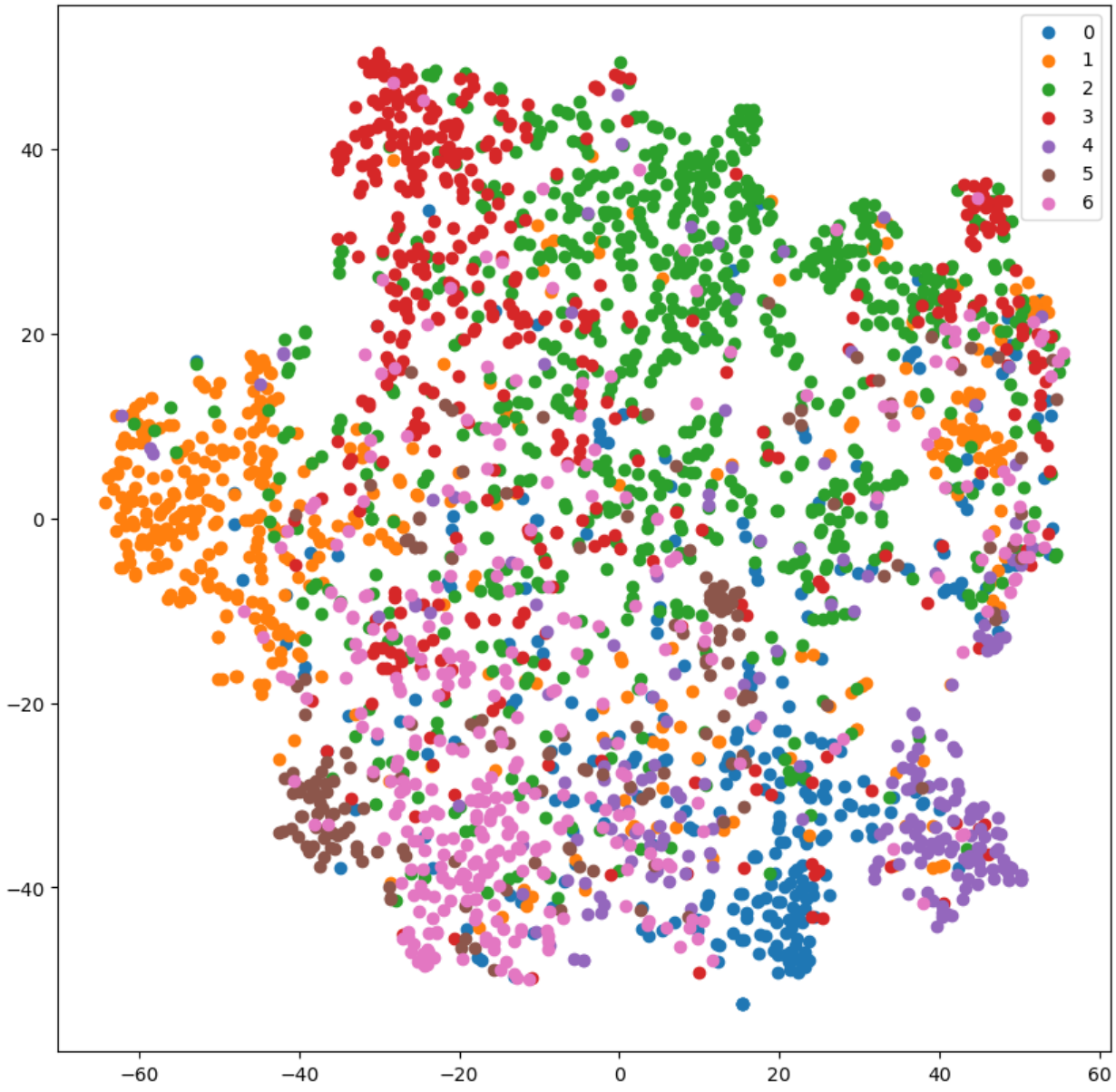
In [ ]:
```
# Evaluate model
y_pred = model_fnn.predict(X_te)
report = classification_report(np.argmax(y_te,axis=1), np.argmax(y_pred,axis=1), target_names=classes)
print('FCNN Classification Report: \n {}'.format(report))
```

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

           Case_Based       0.50      0.58      0.54       114
    Genetic_Algorithms       0.77      0.67      0.72       156
       Neural_Networks       0.73      0.49      0.58       290
 Probabilistic_Methods       0.65      0.55      0.60       172
Reinforcement_Learning       0.43      0.51      0.47        85
         Rule_Learning       0.28      0.77      0.41        60
                Theory       0.44      0.46      0.45       123

              accuracy                           0.55      1000
             macro avg       0.54      0.58      0.54      1000
          weighted avg       0.61      0.55      0.57      1000
```

Get hidden layer representation for FNN

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



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