SamipSinghalFall2021Project

December 12, 2021

[18]:

```

```

1 2021 Fall Semester Project

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Semi - Supervised Learning Using Graph Neural Networks

References:

https://arxiv.org/pdf/1609.02907.pdf

https://github.com/danielegrattarola/spektral/blob/master/examples/node_prediction/citation_gcn.py

https://arxiv.org/abs/2006.12138

https://graphneural.network/datasets/#citation

https://arxiv.org/abs/1706.02216

1.1 Problem Statement

Solve the problem of :- Classification with 'high accuracy' in 'absence of enough labeled data'

For the purpose of this project, we would like to classify research paper into 7 different classes using only 20 samples for each class.

1.2 Outcome

GCN Outperforms FCNN FCNN F1 Score - 55% GCN F1 Score - 76% The T-SNE Plot of GCN hidden layer representation is much much less scattered as FCNN. Using only 20 labeled examples for each class , GCN outperforms FCNN by 20%.

[ ]:

```
#importing dependencies

import numpy as np
import os
import networkx as nx
from tensorflow.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 GCSConv
from spektral.layers import GATConv
from spektral.layers import GraphSageConv
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
```

1.3 Data Loading and Preprocessing

[2]:

```
#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)
```

2 Parsing the data

[3]:

```
#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', 'Case_Based', 'Genetic_Algorithms',
'Probabilistic_Methods', 'Reinforcement_Learning', 'Rule_Learning',
'Neural_Networks'}

Number of classes:  7
```

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

[4]:

```
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)
```

[5]:

```
#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
```

4 Data Distribution

[6]:

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

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

[7]:

```
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})
```

[8]:

```
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_Based': 58,
'Reinforcement_Learning': 35, 'Rule_Learning': 22})
```

5 Convert the labels to one hot encoding

[9]:

```
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)
```

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

[10]:

```
#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
```

7 Building and Training Graph Convolutional Networks

[25]:

```
# 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 = 10        # Patience for early stopping
```

```python
# Preprocessing operations
A = GraphSageConv.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 = GraphSageConv(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 = GraphSageConv(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(learning_rate=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_4"
________________________________________________________________________________
__________________
 Layer (type)                   Output Shape         Param #     Connected to
================================================================================
==================
 input_11 (InputLayer)          [(None, 1433)]       0           []

 dropout_9 (Dropout)            (None, 1433)         0
['input_11[0][0]']

 input_12 (InputLayer)          [(None, 2708)]       0           []

 graph_sage_conv_4 (GraphSageCo  (None, 16)          45856
['dropout_9[0][0]',
 nv)
'input_12[0][0]']
```

```
 dropout_10 (Dropout)           (None, 16)           0
['graph_sage_conv_4[0][0]']

 graph_sage_conv_5 (GraphSageCo  (None, 7)           224
['dropout_10[0][0]',
 nv)
'input_12[0][0]']

================================================================================
==================
Total params: 46,080
Trainable params: 46,080
Non-trainable params: 0
________________________________________________________________________________
__________________
```

[26]:

```python
# 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 [==============================] - 2s 2s/step - loss: 0.1211 - acc: 0.1214 -
val_loss: 0.3488 - val_acc: 0.2920
Epoch 2/200
1/1 [==============================] - 0s 280ms/step - loss: 0.1052 - acc:
0.3143 - val_loss: 0.3400 - val_acc: 0.4100
Epoch 3/200
1/1 [==============================] - 0s 362ms/step - loss: 0.0996 - acc:
0.4500 - val_loss: 0.3298 - val_acc: 0.4580
Epoch 4/200
1/1 [==============================] - 0s 365ms/step - loss: 0.0957 - acc:
0.5500 - val_loss: 0.3175 - val_acc: 0.5260
Epoch 5/200
1/1 [==============================] - 0s 291ms/step - loss: 0.0922 - acc:
0.6714 - val_loss: 0.3094 - val_acc: 0.5780
Epoch 6/200
1/1 [==============================] - 0s 277ms/step - loss: 0.0905 - acc:
```

```
0.7500 - val_loss: 0.3043 - val_acc: 0.6440
Epoch 7/200
1/1 [==============================] - 0s 283ms/step - loss: 0.0902 - acc:
0.7571 - val_loss: 0.3019 - val_acc: 0.6700
Epoch 8/200
1/1 [==============================] - 0s 296ms/step - loss: 0.0889 - acc:
0.8500 - val_loss: 0.3011 - val_acc: 0.6820
Epoch 9/200
1/1 [==============================] - 0s 354ms/step - loss: 0.0900 - acc:
0.8071 - val_loss: 0.2997 - val_acc: 0.6800
Epoch 10/200
1/1 [==============================] - 0s 333ms/step - loss: 0.0886 - acc:
0.8643 - val_loss: 0.2981 - val_acc: 0.6840
Epoch 11/200
1/1 [==============================] - 0s 282ms/step - loss: 0.0876 - acc:
0.8857 - val_loss: 0.2961 - val_acc: 0.6780
Epoch 12/200
1/1 [==============================] - 0s 282ms/step - loss: 0.0870 - acc:
0.8714 - val_loss: 0.2939 - val_acc: 0.6800
Epoch 13/200
1/1 [==============================] - 0s 279ms/step - loss: 0.0866 - acc:
0.8786 - val_loss: 0.2917 - val_acc: 0.6880
Epoch 14/200
1/1 [==============================] - 0s 280ms/step - loss: 0.0854 - acc:
0.9143 - val_loss: 0.2905 - val_acc: 0.6840
Epoch 15/200
1/1 [==============================] - 0s 283ms/step - loss: 0.0849 - acc:
0.8571 - val_loss: 0.2899 - val_acc: 0.6880
Epoch 16/200
1/1 [==============================] - 0s 320ms/step - loss: 0.0825 - acc:
0.9286 - val_loss: 0.2896 - val_acc: 0.6720
Epoch 17/200
1/1 [==============================] - 0s 350ms/step - loss: 0.0835 - acc:
0.8857 - val_loss: 0.2886 - val_acc: 0.6660
Epoch 18/200
1/1 [==============================] - 0s 309ms/step - loss: 0.0802 - acc:
0.9429 - val_loss: 0.2878 - val_acc: 0.6640
Epoch 19/200
1/1 [==============================] - 0s 282ms/step - loss: 0.0801 - acc:
0.9429 - val_loss: 0.2867 - val_acc: 0.6680
Epoch 20/200
1/1 [==============================] - 0s 281ms/step - loss: 0.0786 - acc:
0.9643 - val_loss: 0.2849 - val_acc: 0.6700
Epoch 21/200
1/1 [==============================] - 0s 285ms/step - loss: 0.0784 - acc:
0.9214 - val_loss: 0.2831 - val_acc: 0.6680
Epoch 22/200
1/1 [==============================] - 0s 316ms/step - loss: 0.0776 - acc:
```

```
0.9500 - val_loss: 0.2805 - val_acc: 0.6820
Epoch 23/200
1/1 [==============================] - 0s 345ms/step - loss: 0.0783 - acc:
0.9071 - val_loss: 0.2781 - val_acc: 0.6980
Epoch 24/200
1/1 [==============================] - 0s 308ms/step - loss: 0.0768 - acc:
0.9286 - val_loss: 0.2754 - val_acc: 0.7100
Epoch 25/200
1/1 [==============================] - 0s 288ms/step - loss: 0.0759 - acc:
0.9357 - val_loss: 0.2732 - val_acc: 0.7160
Epoch 26/200
1/1 [==============================] - 0s 273ms/step - loss: 0.0750 - acc:
0.9429 - val_loss: 0.2719 - val_acc: 0.7140
Epoch 27/200
1/1 [==============================] - 0s 286ms/step - loss: 0.0739 - acc:
0.9500 - val_loss: 0.2716 - val_acc: 0.7180
Epoch 28/200
1/1 [==============================] - 0s 277ms/step - loss: 0.0739 - acc:
0.9429 - val_loss: 0.2723 - val_acc: 0.7060
Epoch 29/200
1/1 [==============================] - 0s 278ms/step - loss: 0.0732 - acc:
0.9571 - val_loss: 0.2727 - val_acc: 0.6940
Epoch 30/200
1/1 [==============================] - 0s 302ms/step - loss: 0.0733 - acc:
0.9571 - val_loss: 0.2726 - val_acc: 0.7000
Epoch 31/200
1/1 [==============================] - 0s 352ms/step - loss: 0.0727 - acc:
0.9286 - val_loss: 0.2716 - val_acc: 0.7080
Epoch 32/200
1/1 [==============================] - 0s 340ms/step - loss: 0.0721 - acc:
0.9357 - val_loss: 0.2693 - val_acc: 0.7180
Epoch 33/200
1/1 [==============================] - 0s 276ms/step - loss: 0.0712 - acc:
0.9357 - val_loss: 0.2663 - val_acc: 0.7260
Epoch 34/200
1/1 [==============================] - 0s 280ms/step - loss: 0.0715 - acc:
0.9500 - val_loss: 0.2633 - val_acc: 0.7460
Epoch 35/200
1/1 [==============================] - 0s 289ms/step - loss: 0.0709 - acc:
0.9357 - val_loss: 0.2616 - val_acc: 0.7480
Epoch 36/200
1/1 [==============================] - 0s 281ms/step - loss: 0.0696 - acc:
0.9643 - val_loss: 0.2605 - val_acc: 0.7440
Epoch 37/200
1/1 [==============================] - 0s 271ms/step - loss: 0.0711 - acc:
0.9357 - val_loss: 0.2608 - val_acc: 0.7340
Epoch 38/200
1/1 [==============================] - 0s 270ms/step - loss: 0.0701 - acc:
```

```
0.9429 - val_loss: 0.2604 - val_acc: 0.7360
Epoch 39/200
1/1 [==============================] - 0s 276ms/step - loss: 0.0691 - acc:
0.9429 - val_loss: 0.2614 - val_acc: 0.7140
Epoch 40/200
1/1 [==============================] - 0s 362ms/step - loss: 0.0695 - acc:
0.9429 - val_loss: 0.2623 - val_acc: 0.7200
Epoch 41/200
1/1 [==============================] - 0s 313ms/step - loss: 0.0705 - acc:
0.9286 - val_loss: 0.2643 - val_acc: 0.7080
Epoch 42/200
1/1 [==============================] - 0s 300ms/step - loss: 0.0689 - acc:
0.9286 - val_loss: 0.2653 - val_acc: 0.7020
Epoch 43/200
1/1 [==============================] - 0s 305ms/step - loss: 0.0707 - acc:
0.9071 - val_loss: 0.2644 - val_acc: 0.7260
Epoch 44/200
1/1 [==============================] - 0s 296ms/step - loss: 0.0706 - acc:
0.9357 - val_loss: 0.2630 - val_acc: 0.7440
Epoch 45/200
1/1 [==============================] - 0s 289ms/step - loss: 0.0702 - acc:
0.9214 - val_loss: 0.2620 - val_acc: 0.7440
Epoch 46/200
1/1 [==============================] - 0s 295ms/step - loss: 0.0694 - acc:
0.9500 - val_loss: 0.2607 - val_acc: 0.7520
Epoch 47/200
1/1 [==============================] - 0s 287ms/step - loss: 0.0686 - acc:
0.9714 - val_loss: 0.2595 - val_acc: 0.7580
Epoch 48/200
1/1 [==============================] - 0s 266ms/step - loss: 0.0688 - acc:
0.9714 - val_loss: 0.2593 - val_acc: 0.7520
Epoch 49/200
1/1 [==============================] - 0s 282ms/step - loss: 0.0689 - acc:
0.9429 - val_loss: 0.2610 - val_acc: 0.7420
Epoch 50/200
1/1 [==============================] - 0s 274ms/step - loss: 0.0705 - acc:
0.9143 - val_loss: 0.2636 - val_acc: 0.7280
Epoch 51/200
1/1 [==============================] - 0s 285ms/step - loss: 0.0695 - acc:
0.9429 - val_loss: 0.2657 - val_acc: 0.7200
Epoch 52/200
1/1 [==============================] - 0s 276ms/step - loss: 0.0696 - acc:
0.9286 - val_loss: 0.2659 - val_acc: 0.7140
Epoch 53/200
1/1 [==============================] - 0s 269ms/step - loss: 0.0692 - acc:
0.9571 - val_loss: 0.2659 - val_acc: 0.7180
Epoch 54/200
1/1 [==============================] - 0s 345ms/step - loss: 0.0711 - acc:
```

```
0.9143 - val_loss: 0.2641 - val_acc: 0.7220
Epoch 55/200
1/1 [==============================] - 0s 331ms/step - loss: 0.0694 - acc:
0.9571 - val_loss: 0.2623 - val_acc: 0.7320
Epoch 56/200
1/1 [==============================] - 0s 288ms/step - loss: 0.0692 - acc:
0.9429 - val_loss: 0.2609 - val_acc: 0.7460
Epoch 57/200
1/1 [==============================] - 0s 280ms/step - loss: 0.0710 - acc:
0.9143 - val_loss: 0.2603 - val_acc: 0.7540
Epoch 58/200
1/1 [==============================] - 0s 305ms/step - loss: 0.0682 - acc:
0.9643 - val_loss: 0.2603 - val_acc: 0.7500
```

[26]:
```
<keras.callbacks.History at 0x7fdb2e4da290>
```

[21]:
```python
# 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))
```

```
            ␣
↪---------------------------------------------------------------------------

       ValueError                                Traceback (most recent call␣
↪last)

       <ipython-input-21-3f83555e3485> in <module>
         4 y_te = labels_encoded[test_mask]
         5
   ----> 6 y_pred = model.predict([X_te, A_te], batch_size=N)
         7 report = classification_report(np.argmax(y_te,axis=1), np.
↪argmax(y_pred,axis=1), target_names=classes)
         8 print('GCN Classification Report: \n {}'.format(report))


       ~/opt/anaconda3/lib/python3.7/site-packages/keras/utils/traceback_utils.
↪py in error_handler(*args, **kwargs)
        65     except Exception as e:  # pylint: disable=broad-except
        66       filtered_tb = _process_traceback_frames(e.__traceback__)
   ---> 67       raise e.with_traceback(filtered_tb) from None
        68     finally:
```

```
     69       del filtered_tb


    ~/opt/anaconda3/lib/python3.7/site-packages/tensorflow/python/framework/
↪func_graph.py in autograph_handler(*args, **kwargs)
   1127           except Exception as e:  # pylint:disable=broad-except
   1128             if hasattr(e, "ag_error_metadata"):
-> 1129               raise e.ag_error_metadata.to_exception(e)
   1130             else:
   1131               raise


    ValueError: in user code:

    File "/Users/samipsinghal/opt/anaconda3/lib/python3.7/site-packages/
↪keras/engine/training.py", line 1621, in predict_function  *
        return step_function(self, iterator)
    File "/Users/samipsinghal/opt/anaconda3/lib/python3.7/site-packages/
↪keras/engine/training.py", line 1611, in step_function  **
        outputs = model.distribute_strategy.run(run_step, args=(data,))
    File "/Users/samipsinghal/opt/anaconda3/lib/python3.7/site-packages/
↪keras/engine/training.py", line 1604, in run_step  **
        outputs = model.predict_step(data)
    File "/Users/samipsinghal/opt/anaconda3/lib/python3.7/site-packages/
↪keras/engine/training.py", line 1572, in predict_step
        return self(x, training=False)
    File "/Users/samipsinghal/opt/anaconda3/lib/python3.7/site-packages/
↪keras/utils/traceback_utils.py", line 67, in error_handler
        raise e.with_traceback(filtered_tb) from None
    File "/Users/samipsinghal/opt/anaconda3/lib/python3.7/site-packages/
↪keras/engine/input_spec.py", line 263, in assert_input_compatibility
        raise ValueError(f'Input {input_index} of layer "{layer_name}" is '

    ValueError: Input 1 of layer "model_2" is incompatible with the layer:␣
↪expected shape=(None, 2708), found shape=(None, 1000)
```

8 Get hidden layer representation for GCN

[27]:

```python
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
```

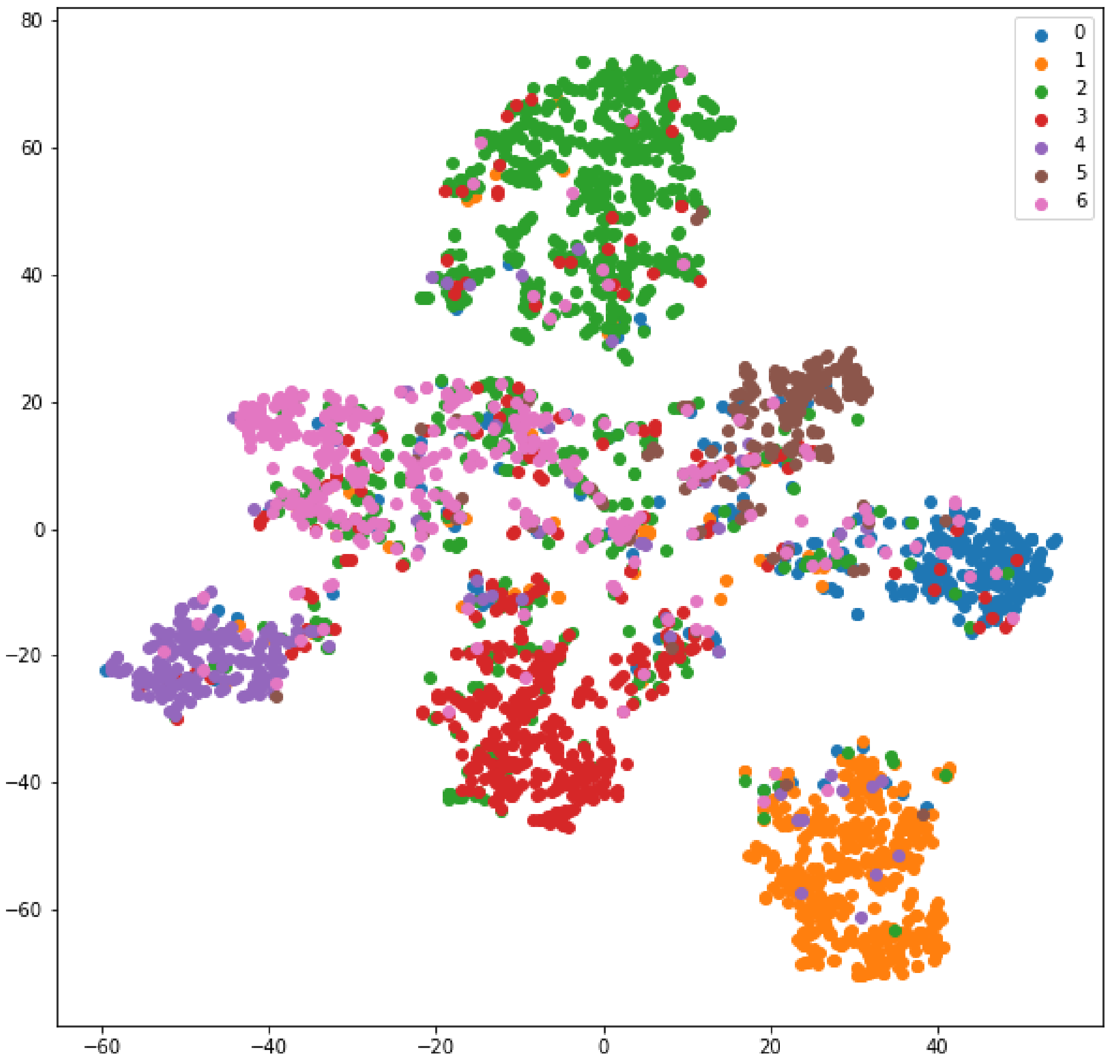
```
x_tsne = TSNE(n_components=2).fit_transform(activations[3])
```

```
/Users/samipsinghal/opt/anaconda3/lib/python3.7/site-
packages/sklearn/manifold/_t_sne.py:783: FutureWarning: The default
initialization in TSNE will change from 'random' to 'pca' in 1.2.
  FutureWarning,
/Users/samipsinghal/opt/anaconda3/lib/python3.7/site-
packages/sklearn/manifold/_t_sne.py:793: FutureWarning: The default learning
rate in TSNE will change from 200.0 to 'auto' in 1.2.
  FutureWarning,
```

[28]:

```
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)
```



9 Comparison to Fully-Connected Neural Networks

[31]:
```
es_patience = 10
optimizer = Adam(learning_rate=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 [==============================] - 1s 831ms/step - loss: 0.2184 - acc:
0.1643 - val_loss: 0.4328 - val_acc: 0.2680
Epoch 2/200
1/1 [==============================] - 0s 86ms/step - loss: 0.1749 - acc: 0.3571
- val_loss: 0.3976 - val_acc: 0.3640
Epoch 3/200
1/1 [==============================] - 0s 86ms/step - loss: 0.1386 - acc: 0.6143
- val_loss: 0.3607 - val_acc: 0.5480
Epoch 4/200
1/1 [==============================] - 0s 92ms/step - loss: 0.1127 - acc: 0.7000
- val_loss: 0.3231 - val_acc: 0.6040
Epoch 5/200
1/1 [==============================] - 0s 108ms/step - loss: 0.0821 - acc:
```

```
0.8071 - val_loss: 0.2881 - val_acc: 0.6120
Epoch 6/200
1/1 [==============================] - 0s 106ms/step - loss: 0.0687 - acc:
0.8286 - val_loss: 0.2614 - val_acc: 0.6080
Epoch 7/200
1/1 [==============================] - 0s 110ms/step - loss: 0.0550 - acc:
0.8786 - val_loss: 0.2545 - val_acc: 0.5960
Epoch 8/200
1/1 [==============================] - 0s 111ms/step - loss: 0.0469 - acc:
0.9429 - val_loss: 0.2707 - val_acc: 0.5700
Epoch 9/200
1/1 [==============================] - 0s 100ms/step - loss: 0.0441 - acc:
0.9500 - val_loss: 0.2940 - val_acc: 0.5720
Epoch 10/200
1/1 [==============================] - 0s 104ms/step - loss: 0.0415 - acc:
0.9929 - val_loss: 0.3226 - val_acc: 0.5600
Epoch 11/200
1/1 [==============================] - 0s 105ms/step - loss: 0.0429 - acc:
0.9786 - val_loss: 0.3547 - val_acc: 0.5380
Epoch 12/200
1/1 [==============================] - 0s 113ms/step - loss: 0.0447 - acc:
0.9786 - val_loss: 0.3728 - val_acc: 0.5360
Epoch 13/200
1/1 [==============================] - 0s 110ms/step - loss: 0.0413 - acc:
0.9929 - val_loss: 0.3805 - val_acc: 0.5320
Epoch 14/200
1/1 [==============================] - 0s 119ms/step - loss: 0.0394 - acc:
0.9857 - val_loss: 0.3795 - val_acc: 0.5420
Epoch 15/200
1/1 [==============================] - 0s 123ms/step - loss: 0.0372 - acc:
0.9786 - val_loss: 0.3792 - val_acc: 0.5520
Epoch 16/200
1/1 [==============================] - 0s 94ms/step - loss: 0.0334 - acc: 1.0000
- val_loss: 0.3761 - val_acc: 0.5660
Epoch 17/200
1/1 [==============================] - 0s 101ms/step - loss: 0.0310 - acc:
1.0000 - val_loss: 0.3773 - val_acc: 0.5580
```

[31]:
```
<keras.callbacks.History at 0x7fdb0d4a1ed0>
```

[32]:
```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       0.50      0.56      0.53       114
    Genetic_Algorithms       0.75      0.71      0.73       156
       Neural_Networks       0.72      0.54      0.62       290
Probabilistic_Methods       0.70      0.50      0.58       172
Reinforcement_Learning       0.54      0.52      0.53        85
         Rule_Learning       0.42      0.60      0.49        60
                Theory       0.34      0.60      0.44       123

              accuracy                           0.57      1000
             macro avg       0.57      0.58      0.56      1000
          weighted avg       0.62      0.57      0.58      1000
```

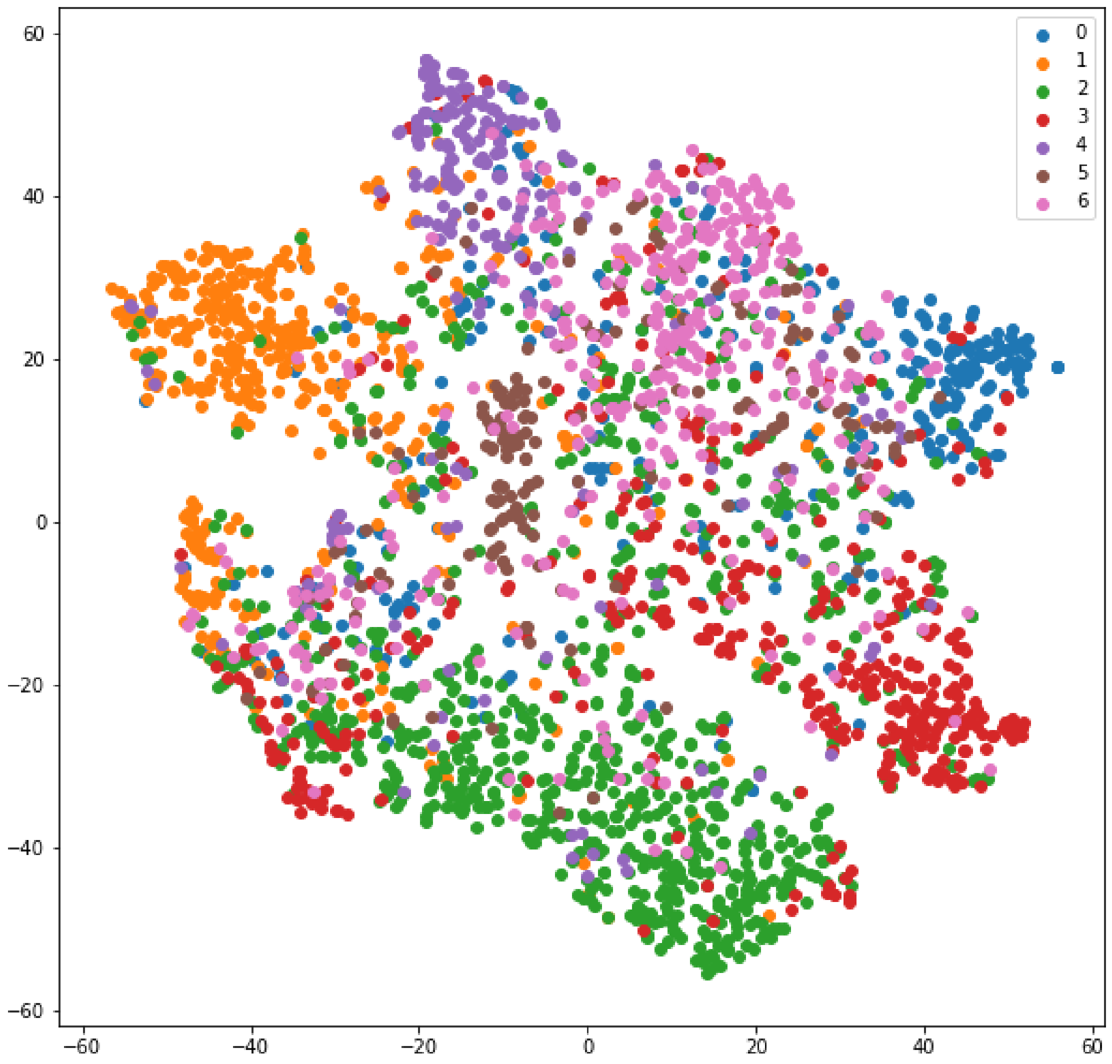
[33]:

```
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])
```

[34]:

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

```
/Users/samipsinghal/opt/anaconda3/lib/python3.7/site-
packages/sklearn/manifold/_t_sne.py:783: FutureWarning: The default
initialization in TSNE will change from 'random' to 'pca' in 1.2.
  FutureWarning,
/Users/samipsinghal/opt/anaconda3/lib/python3.7/site-
packages/sklearn/manifold/_t_sne.py:793: FutureWarning: The default learning
rate in TSNE will change from 200.0 to 'auto' in 1.2.
  FutureWarning,
```


60
40
20
0
−20
−40
−60
−60
−40
−20
0
20
40
60
● 0
● 1
● 2
● 3
● 4
● 5
● 6

[ ]: