Friend Recommendation using Graph Neural Networks in Social Platforms

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# Introduction

Social networks play a pivotal role in connecting individuals, and the task of friend recommendation within these networks is crucial for enhancing user experience. This project aims to address the challenge of friend recommendation using Graph Neural Networks (GNNs). The objective is to leverage GNNs to predict and rank potential new friends for users within social networks, particularly focusing on dataset from Facebook, Google+, and Twitter.

The primary challenge is to develop a friend recommendation system capable of providing accurate and effective suggestions within the given social networks. The anonymized nature of the data introduces complexities in understanding individual characteristics, and the large-scale network necessitates scalable algorithms.

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# Methodology

The dataset was obtained through McAuley and Leskovec prior work on social circles in ego networks, currently hosted on the Stanford SNAP dataset library.

Figure 1 This ego-network contains users, features and social circles from Facebook. The task aims to adjust the features and user embeddings and calculate the ranking of friends.   
Source: http://i.stanford.edu/~julian/pdfs/nips2012.pdf

It includes user to user connections / interactions, denoted as edges (nodeId.edges), communities (nodeId.circles), features for each of the users represented as nodes (nodeId.feat), features for the ego user (nodeId.egofeat) and names of each of the feature dimensions (nodeId.featnames) from Facebook, Google+, and Twitter. Nodes, features (profiles), circles, and ego networks have been anonymized to ensure user privacy. The dataset anonymization is achieved by replacing original IDs and obscuring feature interpretations. Table 1 provides a brief description of the aforementioned datasets:

| Attributes | Data Set | |
| --- | --- | --- |
| Facebook | Twitter |
| Nodes | 4.039 | 81.306 |
| Edges | 88.234 | 1.768.149 |
| Node Features | 1.406 | 216.839 |
| Average clustering coefficient | 0,6055 | 0,5653 |
| Diameter | 8 | 7 |
| 90-percentile effective | 4,7 | 4,5 |

Table 1. Dataset

## Data Pre-Processing

The data processing approach involved several key steps to enhance the dataset for subsequent analysis. The ego features were unified with the user features to create a cohesive representation of individual user characteristics. Then, the featnames were mapped to their respective feature names for each column, establishing a clear association between feature identifiers and their names. As part of the process, all networks were consolidated to create a final, integrated file. This file incorporates all features precisely aligned with their respective names.

The refined dataset serves as a valuable resource for model training and facilitates further in-depth analysis within our science report. The processed data file is ready to contribute significantly to the exploration and creation of the Data Graph within the network.

Subsequently, a custom dataset class derived from PyTorch Geometric data processing library was defined to encapsulate the data and store them in memory of the appropriate processing device (CPU or GPU, if CUDA is available and enabled). This class object represents a graph compatible with PyTorch Geometric, suitable for training, validation and experimentation with graph neural networks.

## Graph Neural Networks Background

Graph Neural Networks (GNNs) are a category of neural networks specifically designed for processing and learning from graph-structured data. In contrast to conventional neural networks, which primarily operate on grid-structured or sequential data, GNNs are tailored to handle data represented as graphs composed of nodes (vertices) interconnected by edges (links). They have garnered significant attention due to their efficacy in modeling intricate relationships and dependencies inherent in data with irregular structures, such as social networks, biological networks, recommendation systems, and knowledge graphs. GNNs facilitate various tasks including node classification, link prediction, graph classification, and graph generation.

At their core, GNNs employ an iterative approach to update node representations by aggregating information from neighboring nodes within the graph. This iterative process enables GNNs to capture the local graph structure and propagate information across the entire graph. A multitude of architectural designs and techniques have been proposed to realize this concept, including Graph Convolutional Networks (GCNs), Graph Attention Networks (GATs), GraphSAGE, Graph Isomorphism Networks (GINs), among others.

Our approach on the friendship recommendation model is split into a GCN model to learn node embeddings, and a friend ranking model to utilize node embeddings knowledge for friendship suggestion based on higher relevancy ranking score. Finally, the GCN model effectiveness was evaluated against a baseline TruncatedSVD model for the same task of learning node embeddings.

## Graph Convolutional Network Model

In the context of modeling the learning process for node embeddings, a graphical model of a neighborhood neural network was developed, focusing on the analysis of social networks through the Facebook platform, as derived from the Facebook dataset. The model is based on a Graph Convolutional Network (GCN) and is designed to learn information about the users and calculate features for each node based on the neighbor nodes. The fundamental concept is to perform convolution on the k-neighbor node features while maintaining the structural connections between nodes. First, the model receives data from the Facebook dataset, which includes relationship connections between users and user features. The input is represented as a graph, with users as nodes and connections as edges.

Incorporated within the model are two hidden layers employing graphical convolutions, with ReLU activations and a dropout layer in between. This allows extracting important features from the graph and user features. Additionally, a Stochastic Gradient Descent optimizer is utilized as well as a StepLR scheduler to control the learning rate decay. At the final output level, the loss is minimized from the calculations of positive and negative scores against the accuracy of the predictions of relationships between users.

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The additional baseline model used as reference was designed based on the TruncatedSVD model. TruncatedSVD is based on dimensionality reduction while preserving the most important information in the data. Truncated SVD is applied in collaborative filtering-based recommendation systems to handle sparse user-item interaction matrices efficiently. It helps in identifying latent factors or features that represent user preferences and item characteristics, enabling more accurate recommendations, thus, making it a suitable comparison model to the GCN implementation. It features the same SGD optimizer and StepLR scheduler as the GCN model.

## Friend Ranking Module

After training the model to obtain embedded representations of the nodes, the next objective is a prediction model for estimating the "likelihood" of two nodes connecting, by calculating the dot product between the two nodes embeddings.

The Friend Ranking Module utilizes as input the edge index matrices, and the node features h, as learnt from the GCN/TruncatedSVD model. For each edge pairing, the module maps the features with the source node and the destination node.

Subsequently, it calculates the dot product between the two embeddings pairings. The dot product provides a score measurement indicating the "agreement" between these features. In the context of graph representation, this is interpreted as an indication of the probability of a connection between the two nodes, denoted as an edge between the two nodes in the graph.

# experiments

In this section, we present the experiments of this study. We report on our experimental setup, describing in detail the datasets we used as input and how we preprocess them, the evaluation metrics we used to assess the model’s effectiveness in recommending new user-to-user connections along with the model’s training process. Following this, we present the cross evaluation GNN model we utilized to test against our GCN model implementation, Truncated Singular Value Decomposition. Lastly, we showcase the results of our comprehensive experiments, state our observations and offer insights.

## Experimental Setup

### Dataset

We evaluated the proposed GCN model utilizing two large-scale datasets as authored by [CITATION] and stored on Stanford’s SNAP repository. The datasets contained information about ego networks on Facebook and Twitter and each dataset was subjected to different preprocessing before use.

The ego-Facebook dataset contained information about 10 anonymized ego networks, with 4.039 nodes, 88.234 edges and 1.406 features describing each node, as presented on [TABLE X]. The dataset was restructured into a file representing the node features matrix by combining the data contained in the “.egofeat”, “.feat” and “.featnames” files into a space separated file of 1.406 columns for each feature and 4.039 lines for each node, comprised of zeros and ones, along with the provided “facebook\_combined.txt” containing the information about the graph connectivity.

In sequence, the dataset was loaded into the graph representing PyTorch Geometric helper class “Data”, which was used to procure the train and test True Negatives through the build-in negative\_sampling function, along with a subgraph containing 70% of the original edges, to procure the training True Positives, while the remaining 30% was utilized to provide the test True Positives. This selective, highly curated separation process is necessary in contributing to a focused training environment vital for ensuring reliable performance on the ranking metrics utilized in this study.

An alternative approach was utilized for the ego-Twitter dataset preprocessing, due to the large-scale nature of the data, as well as existing hardware limitations. In contrast with the ego-Facebook dataset, the ego-Twitter dataset was encoded in categorical values, which in succession were converted to word embeddings to be loaded through the “Data” class. The remaining sampling procedure was performed unaltered, as described above.

### Evaluation Metrics

This section of the report describes the comprehensive evaluation process of our recommendation system's performance through prediction and ranking metrics.

These metrics serve a crucial role in measuring the accuracy of the model’s capability in identifying potential new user connections / friendships, along with the effectiveness of our model in predicting the top relevant neighbor users that are likely to attract the stakeholder users' interest. Additionally, the metrics provide valuable insights into the system's optimization potential, facilitating ongoing improvements for enhanced user satisfaction.

Specifically, the metrics utilized for evaluating the recommendation model are distinguished into two types:

#### Accuracy Based Metric: the model's performance is evaluated on the test set using the Area Under the Curve (AUC) metric. AUC is a statistical metric representing the area under the receiver operating characteristic (ROC) curve, where higher values indicate better discrimination between classes.

#### Ranking Based Metrics: Friend recommendation tasks are sensitive to effective link predictions in both quality and the ranking position in the top K predictions. Specialized metrics are nessesary for this quantative evaluation, since standard accuracy metrics do not consider the position in the top K predictions. To rectify this shortfall, the following metrics will be used:

* Hits@K: Measures the proportion of relevant items among the top k recommendations, providing insights into the system's ability to retrieve relevant items within a given recommendation list. *It is calculated through the following formula:*
* NDCG@K (Normalized Discounted Cumulative Gain): Evaluates the ranking quality of the recommendations at position K*,* by considering both relevance and position, offering a more nuanced assessment of the ranking quality. *NDCG@K is computed as:*
* MRR (Mean Reciprocal Rank): Assesses the effectiveness of the recommendation by considering the rank of the first correct recommendation*, as determined by the ensuing equation:*

### Training Process

Our model is trained using a configuration comprising layers of message passing graph convolutional operations, each possessing a hidden dimension size of 64 and an output embedding dimension of 64. Within each layer, the aggregation of information from neighboring nodes occurs through a weighted sum calculation of their respective features. Subsequently, dimensionality reduction is executed on the aggregated data via a linear transformation neural network layer, augmented with the ReLU activation function. A dropout, with a default rate of 0.5, is applied between layers during model training.

The training process involves conducting a series of experiments across epochs, encompassing 30, 50, 100, 200 and 1000 maximum epochs. A Stochastic Gradient Descent optimizer, coupled with a learning rate of 0.01 and momentum of 0.9, is employed for this purpose. Additionally, a learning rate decay of 0.5 is applied every 25 epochs using the StepLR scheduler.

The experimental evaluation is conducted on two distinct machines: one equipped with an AMD Ryzen 7 2700 Eight-Core Processor, featuring 2 threads per core and 8 GB of shared CPU memory, operating on the Ubuntu Linux 20.04.6 LTS platform, and the other utilizing an Intel Core i7 6700K 4 core Processor featuring 2 threads per core and 16 GB of shared CPU memory, operating on the Windows 10 platform.

Notably, our PyTorch Geometric implementation is made publicly available through the GitHub repository.

## Cross Evaluation Baseline

Aspiring to further evaluate the GCN model effectiveness, we performed a cross evaluation comparison versus the Truncated Singular Value Decomposition (tSVD) model for dimensionality reduction.

Truncated Singular Value Decomposition (SVD) is a mathematical technique used for reducing the dimensionality of a matrix while preserving its essential structure. It involves decomposing a matrix into three constituent matrices - the left singular vectors, the singular values, and the right singular vectors. The "truncated" aspect of this method involves retaining only the top k singular vectors and corresponding singular values, effectively reducing the dimensionality of the original matrix.

Truncated SVD finds applications in various fields, including data compression, noise reduction, feature extraction, and latent semantic analysis. It is widely utilized in machine learning tasks in recommendation systems where high-dimensional data matrices are common and reducing their dimensionality can improve computational efficiency and facilitate interpretation. By retaining the most significant information encoded in the original matrix, truncated SVD enables more efficient and effective analysis of large datasets while mitigating the effects of noise and redundancy.

In our implementation tSVD performs dimensionality reduction from the input dimension of 1406 to output dimension of 64 accompanied by a linear transformation. The training process remained the same between tSVD and GCN models to provide consistent and comparable results.

## Experiment Results

The presented table [X] showcases the performance metrics for the two models, GCN and tSVD, across the various evaluation criteria, as stated in training epochs and accuracy / ranking evaluation metrics.

The observations and insights based on the provided results can be summarized as following:

1. Table Type Styles

| 30 training Epoch | | | | | |
| --- | --- | --- | --- | --- | --- |
| Model | AUC | Hits | NDCG | MRR | Ranking |
| GCN | 0.8877 | 0.0090 | 0.0260 | 0.0209 | Top 5 |
| 0.0064 | 0.0640 | 0.0305 | Top 50 |
| tSVD | 0.7545 | 0.0046 | 0.0143 | 0.0117 | Top 5 |
| 0.0037 | 0.0407 | 0.0180 | Top 50 |

1. Example of a figure caption. (*figure caption*)

| 50 training Epoch | | | | | |
| --- | --- | --- | --- | --- | --- |
| Model | AUC | Hits | NDCG | MRR | Ranking |
| GCN |  |  |  |  | Top 5 |
|  |  |  | Top 50 |
| tSVD |  |  |  |  | Top 5 |
|  |  |  | Top 50 |

1. Example of a figure caption. (*figure caption*)

| 100 training Epoch | | | | | |
| --- | --- | --- | --- | --- | --- |
| Model | AUC | Hits | NDCG | MRR | Ranking |
| GCN | 0.9316 | 0.009 | 0.0252 | 0.0192 | Top 5 |
| 0.0086 | 0.0761 | 0.0318 | Top 50 |
| tSVD | 0.7861 | 0.0047 | 0.0143 | 0.0114 | Top 5 |
| 0.0042 | 0.0434 | 0.0184 | Top 50 |

1. Example of a figure caption. (*figure caption*)

| 200 training Epoch | | | | | |
| --- | --- | --- | --- | --- | --- |
| Model | AUC | Hits | NDCG | MRR | Ranking |
| GCN | 0.9417 | 0.011 | 0.0319 | 0.0253 | Top 5 |
| 0.0094 | 0.0861 | 0.0395 | Top 50 |
| tSVD | 0.8224 | 0.0055 | 0.0166 | 0.0134 | Top 5 |
| 0.0046 | 0.0475 | 0.0212 | Top 50 |

1. Example of a figure caption. (*figure caption*)

| 1000 training Epoch | | | | | |
| --- | --- | --- | --- | --- | --- |
| Model | AUC | Hits | NDCG | MRR | Ranking |
| GCN | 0.9596 | 0.0096 | 0.0273 | 0.0212 | Top 5 |
| 0.0095 | 0.0868 | 0.036 | Top 50 |
| tSVD | 0.8556 | 0.0043 | 0.0126 | 0.0097 | Top 5 |
| 0.0048 | 0.0448 | 0.017 | Top 50 |

1. Example of a figure caption. (*figure caption*)

#### Model Accuracy: GCN achieves a notably higher AUC score (88.77% to 95.96%) compared to tSVD (75.45% to 85.56%). This suggests that GCN demonstrates superior discriminatory power in distinguishing positive and negative instances.

#### Ranking Relevancy, top 5 results: GCN outperforms tSVD across all three metrics Hits (GCN 0.009-0.011 versus tSVD 0.0043-0.0055), NDCG (GCN 0.0252-0.0273 versus tSVD 0.0126-0.0166) and MRR (GCN 0.0209-0.0253 versus tSVD 0.0097-0.0134). GCN's higher values indicate better performance in accurately recommending relevant items within the top-5 recommendations.

#### Ranking Relevancy, top 50 results: Similar to the Top-5 metrics, GCN also outperforms tSVD across all three metrics Hits (GCN 0.0064-0.0095 versus tSVD 0.0037-0.0048), NDCG (GCN 0.064-0.0868 versus tSVD 0.0407-0.0475) and MRR (GCN 0.0305-0.0395 versus tSVD 0.017-0.0212). This implies that GCN maintains its superiority in recommending relevant items across a larger set of recommendations (Top-50).

#### Max epoch training strategies: Across both models, longer training sessions improve the model prediction performance, as seen in AUC results, with ranking relevancy peaking at 200 epochs, with further training impeading on the ranking relevancy performance, as viewed on the figure [X].

#### Alternative approach, Twitter Dataset: Experimental results on the alternative preprocessed dataset ego-Twitter proved inconsistent, with AUC results on GCN model of 50% accuracy, while tSVD model failed to converge to solution. Hence, the application of ranking metrics was unwarranted in this particular scenario due to the model’s inability to predict new user-to-user connections.

In summary, based on the experimental results, GCN proves to be a more effective model for friend recommendation in the ego-Facebook social network graph compared to tSVD. The higher AUC score and consistently better performance across various top-K recommendation metrics indicate the superior predictive and ranking capabilities of GCN. Extensive training sessions increase the model accuracy, with exceptions on ranking relevancy peaking at 200 epochs and further decreasing over time.

# Discussions

Interpret results. Compare with grafrank. Performance. Limitations. Future work.

# Conclusions

Conclusions paragraph.

##### References

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