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学位(専攻分野)	博士(情報学)
学 位 記 番 号	総研大甲第 2361 号
学位授与の日付	2022 年 9 月 28 日
学位授与の要件	複合科学研究科　情報学専攻 学位規則第6条第1項該当
学 位 論 文 題 目	Modeling Rating Relation Vectors in User-Item Interaction for Hybrid Collaborative Filtering
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(Form 3)

Summary of Doctoral Thesis

Name in full : Phannakan TENGKIATTRAKUL

Title: Modeling Rating Relation Vectors in User-Item Interaction for Hybrid Collaborative Filtering

Recommender systems (RSs) are the systems that were developed to provide a personalized recommendation on the suitable items that would be satisfied by an individual user. In recent years, as the amount of information created by people's daily activities has increased, users have found it challenging to select products that best suit them from among several options available. As a result, RSs have been developing over the years to solve the problem of information overload. Nowadays RSs have become an important engine for many platforms, e.g. e-commerce, online news, and social network sites (SNS).

There are many approaches in RSs. The most popular approach for recommending items to a target user (the user to whom recommendations are targeted) is the collaborative filtering (CF) approach, which is based on the similarity of users or items from previous interactions. It utilizes historical interaction (e.g., clicks, rates, purchases, etc.) to infer the user's preference and recommends items based on the matching score between the target user and the target item.

Typically, CF can be divided into two approaches: a neighborhood-based approach and a model-based approach. Although the neighborhood-based approach is simple and works reasonably well in practice, it requires a high cost in terms of computing time and space complexity. Also, it can suffer from sparsity problems, which is one of the challenges in the RSs field. Therefore, nowadays, a model-based approach has gained more popularity than a neighborhood-based approach because it is more capable of handling the problem of sparsity and scalability. However, the model-based approach requires a great resource to develop the model and may lose information when performing dimensionality reduction. In addition, the model-based approach still suffers from interpretability and lack of explainability.

From the previous paragraph, it indicates that both the neighborhood-based approach and model-based approach have both advantages and disadvantages. In this thesis, I propose a hybrid CF model that leverages and preserves the advantages of both neighborhood-based and model-based approaches while overcoming their disadvantages. Therefore, this thesis focuses on solving the problems in both the neighborhood-based approach and model-based approach and focuses on how to combine them into the hybrid CF model.

In the neighborhood-based approach, people in the real world tend to believe

their friends' opinions when making decisions. Therefore, in CF RSs, the target user's friends might have an impact on the target user when making decisions on items. Based on this real-world assumption, RSs utilize the opinions of friends to predict how much the target user would like an item.

Typically, the neighborhood-based approach utilizes user rating data to compute the similarity between users or items. In order to predict the rating score of the user toward the target item, CF RS aims to identify the set of the target user's friends and use their actual rating scores to determine how much the target user would like the target item. There are several approaches to finding a set of friends. In case there is no explicit friendship relation in the dataset, most RSs often aim to find the set of users who have rated the target item in the past or have mutually rated items with the target user. Then, the predicted rating score for the target user toward the target item is calculated using the actual scores of friends. However, directly utilizing the actual rating scores from friends often leads to low-accuracy predictions because of the improper rating-range problem.

The improper rating-range problem occurs when the range of rating patterns of each user is different. Because each user has a unique rating pattern, a rating score needs to be interpreted. Even if two users give the same item the same score, it does not always indicate they like it to the same extent if their rating patterns are different. As a result, utilizing the actual ratings from users who rate items within different ranges to predict the rating score of the target user is ineffective and may result in low recommendation accuracy. Therefore, some researchers adjust the ratings from several ranges to match the common range in advance before using them in the prediction step. These methods can be called rating conversion.

Aside from the improper rating-range problem, there is one more problem to consider because each of the target user's friends is likely to have a different level of influence on the target user. In the real world, everyone has biases. It is common to say that all friends are not equal, with user A having more or less influence on the target user than user B. Therefore, there should be a module that helps the model in modifying each friend's rating score to match the target user's perspective before using their scores in the calculation. This can address the issue of improper rating-range. Then, to account for each friend's different influence level, such module should assign an individual weight to each user based on the relation between each friend and the target user-item pair.

For neighborhood-based CF and such rating conversions, the most essential input is ratings that represent the degree of users' interest in an item. For evaluating the performance of RSs, there are two popular approaches, which are rating prediction and item ranking. Item ranking has recently become more popular because some datasets contain implicit feedback and most recent works focus on implicit feedback. Implicit feedback is the interaction between a user and an item that does not have a rating score

(i.e., click, buy, rate, etc.). However, some methods have treated explicit feedback as implicit feedback which I believe would be preferable if the model could leverage and make the most use of the data in the form of explicit feedback rather than transforming it into the implicit feedback form. Because explicit feedback or ratings are more expressive and more powerful than implicit feedback. Each rating score might imply a different meaning. Therefore concrete ratings are important for prediction in RSs.

Although some works use explicit ratings in their neural network (NN) models, they only use ratings as labels for optimization. Those ratings are not directly incorporated as input and don't play an important role in their model. Also, their user and item representations are usually in the form of one-hot vectors which do not indicate specific characteristics of user's ratings or item's ratings. This thesis incorporates ratings as an input of this end-to-end CF model and specifies the interaction between a pair of user-item in more detail by incorporating rating information.

On the other hand, for the model-based approach, even though some works report that it can provide more accurate results than the neighborhood-based approach, it still has some flaws and weaknesses. Recently, some model-based CF models have usually been implemented based on deep learning. Collaborative metric learning (CML) is one of the model-based CF that tries to assign a user-item pair to the same location in a vector space by reducing the distance between each user-item interaction, in which their scoring function is geometrically restrictive. Because this model tries to fit a user and all his interacted items onto the same point, it causes geometrically congestive and inflexible. This thesis proposes a solution to such problem by utilizing the knowledge graph (KG) embedding approach to learn the latent relation vector between user-item pairs instead of trying to put them into the same point in the vector space.

In summary, this thesis extensively studies the challenges of the improper rating-range problem (a problem in neighborhood-based CF), the geometric inflexibility problem (a problem in model-based CF), and how to utilize neighbors directly into the end-to-end hybrid CF model (a challenge in hybrid CF). The main model of this thesis is Attentive Hybrid Collaborative Filtering for Rating Conversion in RSs (AHCF), which consists of modules that solve the aforementioned problems.

First, an approach to utilize neighbors in a hybrid CF model is proposed. Unlike the traditional existing CF RSs model, the novel user and item representations, called user representation matrix (UR-matrix) and item representation matrix (IR-matrix) are introduced to this model. In order to store neighbors' information which is usually in the form of explicit feedback, UR-matrix and IR-matrix can store and specify characteristics of each user and item, respectively.

Second, in the neighborhood-based CF approach, the issues to consider are: 1) different influence of neighbors on the target user and 2) different rating patterns of users. According to the first issue, all friends' influences are not equal from the target user's perspective. The closest friend should have the most influence on the target user

and should have the highest contribution to the model. Likewise, for the item side, the historical item that is most similar to the target item should have more influence than the less similar historical item. Thus, the friends and historical items selection module are proposed to solve this issue.

In addition to the first issue, the different rating patterns of users are solved in the model as well. Due to the improper rating-range problem that occurs when users have different rating patterns, the rating of friends should be converted into the target user's perspective before prediction. The rating conversion between a pair of users is proposed in the friend module which can be categorized as a user-based CF that first converts friends' ratings to match the target user's perspective and then assigns a nonuniform individual weight to each user. Moreover, the item module which can be categorized as item-based CF is proposed to capture relations between the target item and the target user's historical items based on their similarity.

Third, in the model-based CF approach, we need to consider how to model the relationship between users and items. Some model-based CF techniques try to construct user-item relationships by minimizing the distance between users and items in a vector space. In order to prevent the geometric inflexibility problem, TransE concept, one of the most popular translation-based KG embedding models, is introduced to this proposed model. In this work, the latent relation between a pair of target user-item is constructed from two components: 1) combination between the target user and his/her friends and 2) combination between the target item and the target user's historical items. Then the optimization of this model is done based on TransE idea. The experimental results demonstrate that AHCF provides more effectiveness by generating more accurate recommendations than the existing methods.

In addition to the main work AHCF, this thesis proposes two more models, which are Translation-based Embedding model for Rating Conversion in RSs (TransRS) and Integrating the importance levels of friends into trust-based ant-colony RSs (TrustAnt). TransRS is a hybrid CF model which combines neighborhood-based and model-based CF approach into a model. Although TransRS is a hybrid CF RS, the model architecture is a pipeline model, not an end-to-end model like AHCF. On the other hand, the proposed model TrustAnt is a neighborhood-based CF model that also applies a rating conversion method to solve the improper rating-range problem, which is one of the main challenges of this thesis.

Form8 : Separate Sheet
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Results of the doctoral thesis screening

博士論文審査結果

Name in Full
氏 名　　Phannakan TENGKIATTRAKUL

Title
論文題目　　Modeling Rating Relation Vectors in User-Item Interaction for Hybrid Collaborative Filtering

出願者は，類似利用者のアイテムに対する評価を陽に用いるメモリ型協調フィルタリングと利用者およびアイテムの特徴ベクトルの類似度に基づいてアイテムを推薦するモデル型協調フィルタリングの手法を組み合わせたハイブリッド型協調フィルタリング法を提案した．このモデルは，利用者によって異なる評点パターンを考慮して類似利用者を選択する機能を備え，評点に応じて利用者とアイテムの特徴ベクトルの類似度を調整する幾何的柔軟性を備えている点に新規性がある．

本学位論文は８章より構成され英語で書かれている。

第１章では，本研究が扱う協調フィルタリングの研究の意義，本研究で取り組んだ課題および本研究の主な貢献を示している．まず，膨大な情報が生成される情報社会において協調フィリタリングに代表される情報推薦技術の重要性を述べた後に，本博士論文が取り組んだ３つの課題を示し，それぞれの課題に対する貢献を述べている．

第２章では，協調フィルタリングの概要をまとめている．協調フィルタリングの形式的な定義を示したのち，代表的な協調フィルタリング法であるメモリ型およびモデル型の協調フィルタリングについて述べている．

第３章では，協調フィルタリングの近年の研究動向を述べるとともに，本研究と特に関係の深い，知識グラフの埋め込み表現法の情報推薦システムへの適用，および，利用者の評点のパターンの分析とその正規化に関する研究を概観している．

続く４つの章で本博士論文の主たる貢献を述べている．まず第４章で新たな利用者の特徴表現法を提案している．多くのメモリ型協調フィルタリングでは，利用者を特徴ベクトルで表現し,ベクトルの類似度に基づいて嗜好が類似した利用者を求めることが行われる．本研究では,利用者のアイテムに対する評点の意味は利用者によって異なることに着目し，評点ごとに特徴ベクトルを割り当てる利用者特徴行列を提案し，この行列を求める深層ニューラルネットワークを構築している．

第５章では，メモリ型協調フィルタリングにおいて必要となる類似利用者の選択方法を提案している．まず，ソーシャルネットワークのような利用者間の関係を表す補助データが使用できる場合について，ant colony 最適化アルゴリズムを用いた類似利用者選択法を提案している．次に，４章で提案した利用者の特徴行列に対してアテンション機構を適用し類似利用者を選択する方法を提案している．

第６章では，知識グラフの埋め込み表現法を応用した利用者とアイテムの類似度の計算法を提案している．利用者のアイテムに対する評点が高いほど利用者とアイテムの特徴ベクトルの類似度が高くなる必要がある．本論文では，評点に基づいて利用者とアイテムの

関係を表すために関係ベクトルを導入することを提案している．これにより特徴空間において利用者とアイテムの関係を柔軟に表現することを可能にしている．

第７章では，４章から６章で提案した手法を統合した協調フィルタリング用 end-to-end 深層ニューラルネットワークモデルを提案し，協調フィルタリングの評価に用いられる３つの既存データセットを用いた評価によってその有効性を実験的に示している．

第８章で以上の結果をまとめている．

公開発表会では博士論文の構成に沿って発表が行われた．その後に行われた論文審査会および口述試験では，審査員からの質疑に対して適切に回答がなされた．

質疑応答後に審査委員会を開催し審査委員で議論を行った．博士論文審査の結果，出願者は情報学分野の十分な知識と研究能力を持つと認められた．研究内容は、利用者の評点パターンを考慮した新たな協調フィルタリング手法を提案するものであり、モデルの新規性に加え、既存手法に比べ情報推薦精度が向上することを実験的に示しており実用面での貢献も期待できる．また、本学位論文の成果は，国際学術雑誌に１編，査読付き国際会議に２編の主著論文が採択されており，学術的な貢献も認められる．以上の理由により，審査委員会は本学位論文が学位の授与に値すると判断した．