Information Sciences 476 (2019) 19–37

Contents lists available at ScienceDirect

Information Sciences

journal homepage: www.elsevier.com/locate/ins

Visual appearance or functional complementarity: Which aspect affects your decision making?

Bin Wu, Yangdong Ye*, Yun Chen

School of Information Engineering, Zhengzhou University, Zhengzhou 450001, PR China

ARTICLE INFO

Article history:
Received 1 December 2017
Revised 10 August 2018
Accepted 7 October 2018
Available online 9 October 2018

Keywords:
Recommender system
Matrix factorization
Visual appearance
Complementary relationships

ABSTRACT

A personalized product recommendation can significantly help customers find their preferred items and assist business owners in obtaining more income. However, due to the complexity of the users' decision-making process, which is influenced by various aspects in different item domains such as functional complementarity and visual compatibility, item recommendations usually suffer from many challenging problems. Although several visually-aware recommendation methods have been proposed, most do not simultaneously incorporate both the influence of functional complementarity and the effect of visual compatibility into latent factor models. To address this issue, we first build an item-complementarity network using "*frequently-bought-together*" item information. Then, a Visual and Relational Probabilistic Matrix Factorization (VRPMF) model is proposed, which models a user's preference for a given item as the combination of visual contents and item-complementarity relationships. Due to the dynamic nature of online data, such a comprehensive model poses efficiency challenge in learning parameters of the model. To overcome this scalability issue, we present a novel and Fast Alternating Least Squares (FALS) algorithm, to efficiently optimize the proposed model. Finally, to evaluate the VRPMF method, we conduct comprehensive experiments with several state-of-the-art competitors and evaluation metrics on multiple real-world datasets. The empirical results show that our method achieves significant improvements in terms of both rating prediction accuracy and running time. Our implementation of VRPMF is publicly available at: https://github.com/wubin7019088/VRPMF

1. Introduction

Recent years have witnessed a massive supply of online information with the evolution of the Internet. We have encountered a time of information overload, which means that we are always faced with too many choices. Recommender systems are instrumental in tackling this issue, as they can help customers successfully discover the personalized information that matches their preferences. Currently, recommender systems have become an inalienable part of modern e-commence sites (e.g., Amazon [38], Tmall and eBay).

Among existing recommendation techniques, Collaborative Filtering (CF) approaches have been widely used by various applications, due to their relatively simple and effective properties. CF methods attempt to use the observed rating matrix to predict the unknown ratings. Despite having been developed quickly and achieving great success over the past decades, CF

* Corresponding author.
E-mail address: yeyd@zzu.edu.cn (Y. Ye).

https://doi.org/10.1016/j.ins.2018.10.011
0020-0255/

Fig. 1. A target item and its "*frequently-bought-together*" items. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

methods have an important challenge, namely, the cold-start problem [3], which extremely degrades their performance. In recent years, researchers have contributed to improving the effectiveness and efficiency by fusing various types of auxiliary information such as social networks [12,24,28], tag information [2,33,42] and textual reviews [26,39,41].

Users' consumption behaviours are very complex and usually influenced by many internal and external factors [27]; this leads to the inability of the above methods to model a user's true preferences in a fine-grained manner. Consider a real online shopping scenario in which a user rates/buys an item. A high-level question naturally arises: what affects the user's decision making? Answering this question is particularly important when attempting to interpret the human decision-making process and improve the accuracy of rating prediction. The items' intrinsic (e.g., functionality) and extrinsic (e.g., visual appearance) aspects certainly have a crucial effect on users' ratings. However, the extent to which each aspect affects users' preferences varies among item domains. For instance, in visually-aware item domain (e.g., the clothing domain), one wouldn't purchase a cloth from the Amazon site without seeing it. Thus, we consider that the visual appearance of an item plays a leading role compared with other aspects. Meanwhile, in visually non-aware item domain (e.g., office product), it is relatively difficult to make judgements based only on the visual appearance of an item. Undoubtedly, customers would play more attention to the functionality of items. As an intuitive case, Fig. 1 shows examples of items that are frequently bought together in different item domains. Interestingly, in visually-aware item domain (e.g., Amazon Girls and Amazon Men), items that are frequently bought together are visually compatible. Meanwhile, those in visually non-aware item domain (e.g., Office Product and Automotive) are unrelated in terms of visual appearance but are functionally complementary. This phenomenon motivates us to investigate the varying importance of item aspects for users in different item domains.

Recently, building on the success of Deep Learning (DL) methods at learning higher-level representations in computer vision [35], several works [6,11] have successfully taken into account the visual appearances of items for the task of top-n recommendation in visually-aware item domain. However, these methods have not realized large improvements in visually non-aware item domain. This is because each domain has its own aspects that play more important roles in users' decision making, as shown in Fig. 1. Moreover, existing methods only consider visual appearance as side information and are limited in their ability to capture functionally complementary aspect. Especially when the user-item rating matrix is extremely sparse, they eventually degrade the performance of recommendation in visually non-aware item domain. In addition, in handling large-scale data with tens of millions of ratings, scalability inevitably becomes an issue [9]. Most methods utilize Alternating Least Squares (ALS) and Stochastic Gradient Descent (SGD) to optimize Matrix Factorization (MF). However, ALS is not suitable for large-scale data due to the cubic time complexity in the dimensionality of latent factors. Meanwhile, SGD conducts efficiency and simple implementation but requires more iterations to obtain a sufficiently accurate model, and its accuracy is highly sensitive to the selection of the learning rate.

To address the aforementioned issues, based on the assumption that a user's rating will be affected by various aspects in different item domains, we propose a new probabilistic model that integrates item-complementarity network and visual contents for more accurate prediction. Actually, our proposed method is applicable not only to rating prediction, but also to top-n recommendation and many other tasks in machine learning. However, such a comprehensive model poses efficiency challenge in learning parameters of the model. To address this, we specifically develop a novel learning algorithm for efficiently optimizing the proposed model. Our algorithm is analytically k times faster than ALS in computing the proposed model where k denotes dimensionality of latent factors. Another crucial advantage of our algorithm is that it works without a learning rate, bypassing slow convergence for tuning the hyper-parameter such as SGD.

The key contributions of this paper can be summarized as follows: