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Object typicality for effective Web of Things recommendations

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ABSTRACT

With the rapid growth of "Web of Things" (WoT), there is a pressing need to develop effective mechanisms for the intelligent discovery and selection of these things (items). Recommender systems are viable solutions to address the issue of WoT discovery and selection. However, classical recommender systems are weak in handling sparse recommendation spaces which characterize most WoT recommendations. Moreover, classical recommender systems may not be able to scale up to efficiently process a large number of things on the Web, and yet these systems may produce big-error recommendations that diminish users' trusts on utilizing WoT. The main contribution of our research is the design and development of a novel recommendation method which is underpinned by the principle of *object typicality* verified in the field of cognitive psychology to address the aforementioned issues related to WoT recommendations. Based on the MovieLens benchmark data set, our experimental results show that the proposed recommendation method is effective and produces the least big-errors. Since the proposed method exploits data generalization by operating at item group and user group level during recommendation time, it is more effective and efficient than other baseline methods given sparse training data. Based on the Netflix benchmark data set that simulates a large WoT recommendation space, the proposed method also significantly outperforms state-of-the-art recommendation methods in terms of Mean Absolute Error (MAE). The business implication of our research is that the proposed recommendation method can enhance the situation awareness of WoT applications which facilitate the reuse of enterprise resources and the interoperability among enterprises.

1. Introduction

The transition from the Social Web to the Semantic Web has triggered increasingly more physical devices (i.e., smart things) such as RFID chips, wireless sensors, actuators, and mobile phones to be connected to the digital world for the development of useful real-world applications on the Internet (i.e., the "Internet of Things") [12]. More recently, the vision of "Web of Things" (WoT) leads to the design of more sophisticated applications or services by interconnecting any objects through the Web layer (e.g., interconnecting via the HTTP protocol) [8,12]. For example, a movie recommendation service (i.e., a smart thing) is connected to a sensor installed at a cinema; a new WoT application is then composed to timely inform users once tickets of the recommended movies are nearly sold out at that cinema.

However, it has been pointed out that the emerge of a large number of smart things on the Web causes great difficulties to computers as well as humans to find, select, and utilize smart things in an effective way [11,25]. Due to the problem of information overload [19,38,47], it is extremely difficult for Web users to develop the situation awareness about the huge number of things initiated on the Web everyday. Accordingly, there is a pressing need to examine the issue of smart things discovery and selection on the Web. Since recommender systems have been shown to be viable solutions for the discovery and selection of services on the Web [49], this paper focuses on the design and development of a novel recommendation method that can facilitate users (humans or machines) to discover and select relevant smart things. For example, the proposed WoT recommendation service can autonomously suggest some useful things to users based on their previous usage experience and the preferences of other like-minded users.

A large body of research about recommender systems has been performed in the past two decades. Existing recommender systems are usually classified under one of the three broad categories, namely collaborative filtering (CF) [17,36], content-based recommendation (CB) [28,33], and hybrid recommendation [2,24,27]. Content-based recommendation methods suggest items to a user based on similar items s/he having consumed before. On the other hand, collaborative filtering methods recommend items to a user based on the preferences of

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similar users. Hybrid recommendation methods represent a model-based or heuristic-based combination of the aforementioned recommendation methods. Although these recommendation methods have been widely used in electronic commerce, they are faced with the following challenges for WoT recommendations:

- First, data sparsity is a big challenge given few ratings for a large number of items on the Web.
- Second, computational efficiency is another concern given the sheer volume of information about user preferences and items on the Web. Nevertheless, it is desirable for recommender systems to generate recommendations in real-time to facilitate the timely compositions of WoT applications.
- Third, existing recommender systems may generate big-error predictions. In other words, some items suggested by a recommender system are very different from the actual preferences of a user. These big-error predictions diminish users' trusts on WoT applications.

The main contribution of the research work presented in this paper is that we exploit the principle of "object typicality" extensively studied in the field of cognitive psychology [9] to develop a novel, cognitively motivated recommendation method called Recommendation based On Typicality (ROT) to address the aforementioned issues arising in WoT recommendations, and hence to improve the situation awareness of WoT applications. Since recommender systems deal with human perceptions about objects, there is a distinct advantage of designing recommender systems grounded in the principle of human cognition. To the best of our knowledge, this is the first successful design of a cognitively motivated recommender system to enhance WoT recommendations. In particular, ROT exploits high-level item- and user-based similarities to facilitate WoT recommendations. The basic intuition of the proposed method is that a "typical" user of a specific user interest group should be recommended "typical" items that the group is most interested in. For example, a typical user of the "war movies" interest group tends to prefer the typical movies (e.g., "The Longest Day") characterizing the interests of the group.

More specifically, the proposed ROT method first exploits the natural partitions of items of a given recommendation space to establish item groups. Then, the user interest group pertaining to each item group is identified. Finally, items are recommended to a user according to a novel typicality-based computational mechanism that exploits the user's fuzzy memberships pertaining to various user interest groups and the typical items characterizing each of these groups. Pragmatically, items are recommended according to the match between user groups and item groups at execution time. In other words, the ROT method operates at a high level of data granularity (data generalization) [47]. This is a novel way on how ROT addresses the issues of data sparsity and computational complexity arising in WoT recommendations.

The remainder of the paper is organized as follows. Section 2 discusses related research of recommender systems and compares existing work with our proposed approach. The computational details about the proposed object typicality based recommendation method are illustrated in Section 3. In Section 4, we discuss the results of our empirical experiments based on the MovieLens data set[1] and the Netflix data set.[2] We then summarize the main characteristics of the proposed ROT method in Section 5. Finally, we offer concluding remarks and describe future directions of our research work.

2. Related work

2.1. Research on object typicality

Psychologists have found that people are more interested in typical objects than atypical ones when a concept (i.e., a category of objects) is referred to [29]. According to the prototypical view of concepts, each concept is represented by the best prototype capturing the salient properties of objects belonging to that category [26]. Vanpaemel et al. [42] extended the prototypical view of concepts by developing methods to identify the prototypes of a concept based on typical objects. In particular, an object is considered to be an instantiation from the most similar abstraction (prototype). Barsalou [3] proposed two quantitative measures, namely *central tendency* and *frequency of instantiation* to estimate the typicality of an object with respect to a given concept. Central tendency refers to the degree of an object's "family resemblance". An object is considered to have a high central tendency if it is similar to other members of the same category and it is different from the members of other categories. On the other hand, frequency of instantiation refers to the frequency of an object being referred to by people when a specific concept is examined. If an object is often used as an exemplar for a concept, it has a high frequency of instantiation, and therefore it is considered a typical one with respect to that concept.

Rifqi [34] proposed a computational method to estimate object typicality in large databases. In particular, the typicality of an object is estimated according to its resemblance to other members of the same category and its dissimilarities to the members of other categories. Lesot et al. [21] developed a similar computational method in the context of fuzzy systems. Desclés and Pascu [6] applied the notion of object typicality to construct new quantifiers for natural language processing and common sense reasoning. Cai and Leung [5] formalized object typicality with reference to an ontology. Hua et al. [14] applied the principle of object typicality to develop a typicality-based query operator that enhances the effectiveness of query processing in databases.

2.2. Recommender systems

The assumption of content-based recommender systems is that people prefer items similar to those that they positively evaluate before. For content-based recommender systems, the central issue is to examine computational methods for learning user profiles and measuring item similarity. For example, Pazzani and Billsus [33] applied the naive Bayes classifier to construct a user profile that captured "relevant" and "non-relevant" Web pages for the user. Mooney and Roy [28] developed the LIBRA system for the recommendations of books. A detailed account of content-based recommender systems is provided by Pazzani and Billsus [32].

On the other hand, collaborative filtering-based recommender systems suggest items to a user based on the preferences of other like-minded users. Since the collaborative filtering approach does not require well-structured item descriptions, it has been widely used to recommend a variety of items including images, videos, and music [1]. For example, GroupLens [17] and PHOAKS [40] were developed based on the collaborative filtering approach. The user-based CF approach first identifies the nearest "neighbors" of a user by exploiting the user similarity relations. Then, the system predicts the rating of an unrated item based on the ratings given by these nearest "neighbors" [13]. Moreover, Zheng et al. [49] developed a user-based CF approach for the discovery and selection of Web services. In contrast, item-based CF approach recommends items to a user based on other users' ratings of similar items. More specifically, an item-based CF system first identifies the nearest "neighbors" of an unrated item by examining the item similarity relations. Then, the system predicts the rating of the unrated item based on other users' ratings assigned to these nearest "neighbors" of items [7,36].

Hybrid recommender systems combine CB- and CF-based approaches to address the limitations of individual recommendation method [2,27,37]. Melville et al. [27] applied a content-based approach to augment a user-item rating matrix, and then used a collaborative filtering approach to generate the final recommendations. Xue et al. [46] developed a cluster-based Pearson Correlation Coefficient method (SCBPCC) that exploited both item similarity and user similarity in collaborative filtering. Wang et al. [43] proposed the similarity fusion method to unify user- and

[1] http://www.grouplens.org/.
[2] http://archive.ics.uci.edu/ml/datasets.html.