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# Pull-based recommendations in mobile environments

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ABSTRACT

In the field of Context-Aware Recommendation Systems (CARS), only static contextual information is usually considered. However, the dynamic contextual information would very helpful in mobile computing scenarios. Despite this interest, the design and implementation of flexible and generic frameworks to support an easy development of context-aware mobile recommendation systems have been relatively unexplored. In this paper, we describe a framework that facilitates the development of CARS for mobile environments. We mainly focus on the development of the elements needed to support pull-based recommendations and the experimental evaluation of the proposed system.



## 1. Introduction

Recommendation systems [1–3] have become an important research area since their emergence in the last decade of the 20th century. Netflix, MovieLens, Amazon, YouTube, Yahoo, Tripadvisor, Last.fm and IMDb are examples of popular recommendation applications that currently play an important role in the Internet.

In general, a recommendation system is an application that, using certain techniques and algorithms, is able to suggest relevant items to users (e.g., movies, songs, books, jokes, applications, websites, travel destinations, e-learning material, and even friends in social networks). It tries to adapt its proposals to each user in a personalized way, based on his/her preferences and current interests. These recommendations can be seen as a suggestion about items that are considered of potential interest to a particular user. For example, in a scenario of books the recommendations would be books that are expected to be relevant to the user (and so they should be read before others), in a scenario of travel destinations the recommendations would be places that according to the user preferences will be more attractive for the user, in the context of a digital newspaper the recommendations would be the news that the user could find interesting, in the context of movies the recommendations would be movies that the user would probably like, etc.

Traditional recommendation systems ignore the context when providing relevant items to the user. However, the context should play a key role when providing recommendations. Thus, the relevance of an item depends on the context, which notably involves spatio-temporal criteria (e.g., see [4]) but may also include other contextual factors. Moreover, the context of a user in a mobile computing scenario is highly dynamic (e.g., the location of the user usually changes constantly). Therefore, recommendation algorithms should be able to effectively and efficiently exploit the dynamic context of the user in order to offer him/her suitable recommendations.

Our current work is focused on solving the following scientific problem: how could we facilitate the development of *Context-Aware Recommendation Systems* (*CARS*) in mobile environments, to provide users with relevant recommendations? It is motivated by the lack of generic CARS frameworks that consider aspects related to mobile users and mobile computing. So, the goal of our research is to contribute to bridge the gap not only between recommendation systems and context-aware computing, but also between CARS and mobile computing.

In this paper, we describe a framework that facilitates the development of context-aware recommendation systems for mobile users, focusing particularly on pull-based recommendations. The rest of the paper is organized as follows. Section 2 describes the technological context of this work, emphasizing the role of context-aware recommendation systems and mobility, as well as presenting a motivating scenario where a context-aware mobile recommendation framework like the one proposed in this paper would be useful. In Section 3, we overview the context-aware mobile recommendation framework proposed. In Section 4 we focus on the process of pull-based recommendation, which is the main module that we have analyzed and studied in detail in this work. In Section 5, we describe an experimental evaluation that we have performed and the results obtained. In Section 6, we review the

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related work. Finally, we present our conclusions and point out some directions for future work in Section 7.

## 2. Technological context

In this section, we provide an overview of the technological context of our research. First, we introduce some basic ideas about recommendation systems. Then, we focus on context-aware recommendation systems. Afterwards, we consider the introduction of mobility aspects in the recommendations. Finally, we illustrate the interest of mobile context-aware recommendation systems with an example scenario. The goal of this section is to provide background knowledge, rather than the state of the art of research in the area, which is described in Section 6.

### 2.1. Basics of classical recommendation systems (RS)

Depending on how the recommendations are obtained, classical *Recommendation Systems* (*RS*) can be classified into the following categories [5]:

- *Collaborative filtering*: the user receives recommendations of items that people with similar tastes and preferences liked in the past.
- *Content-based recommendation*: the user receives recommendations of items similar to the ones that the user preferred in the past.
- *Hybrid recommendation approaches*: these approaches combine collaborative filtering and content-based recommendation.

Many studies have been performed in the area of recommendation systems. Despite this, the researcher community still continues to develop new approaches, as many interesting problems remain unsolved (e.g., how to obtain suitable recommendations in the absence of previous information about the user, how to ensure enough variability in the items recommended, how to combine and exploit information from other sources such as social networks, etc.). The development of recommendation systems is supported by increasingly-important motivations, especially in the area of businesses (e.g., the need to better understand what the user needs, increase the sales of diverse items, improve the user satisfaction and the user fidelity, etc.) [1].

### 2.2. Basics of context-aware recommendation systems

Most RS operate in a *two-dimensional* (2D) *User* × *Item* space. However, considering only information about the users and items is not enough in applications such as the recommendation of vacation packages. In this case it is important to not only determine which items should be recommended, but also when these recommendations should be provided and how to combine them in a ranked list. Moreover, traditional collaborative filtering techniques generally take into account all the collected ratings of the items to generate the recommendation models; these techniques assume that the context is homogeneous, but actually a user can assign different ratings to the same item in diverse contexts, as the relevance and interest of a specific item for a user may depend on his/her current context. Therefore, additional contextual information should be considered in the recommendation process.

We agree with the context definition provided in [6], which considers the *context* as "any information that can be used to characterize the situation of an entity", where an entity could be "a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves". Other definitions of context have been introduced in the literature related to the context-aware computing field (e.g., [7]). Examples of elements defining the context could be the location, time, weather, mood, activity, and companion of the user. There are certain types of context elements that, according to the circumstances, could be more important than others; for example, if it is raining a person could prefer to stay at home watching a movie rather than to go to run (i.e., the weather element in this case is more important than others).

With advances in the fields of ubiquitous and mobile computing, the lack of analysis of contextual information in recommendation systems has been strongly criticized. So, researchers and developers had mainly focused on solving classic problems of recommendation systems, such as the *cold start* problem, *spam vulnerability*, *high dimensionality*, and many others. Recently, researchers working on recommendation systems have recognized the need to investigate them in domains where the contextual information is particularly relevant, such as in the case of mobile computing scenarios.

The integration of recommendation systems and context-aware computing has given rise to the so-called *Context-Aware Recommendation System* (*CARS*). The meaning of *context-aware* was defined in [6] by indicating that "a system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task".

A pioneer proposal in the field of context-aware recommendation systems is [8,9]. In order to improve the recommendations based on contextual information, the authors of that work extend the classical 2D paradigm to a multidimensional recommendation model (MD model) that provides recommendations based on multiple dimensions: *User* × *Item* × *Context*. They introduced three different context-aware recommendation paradigms, which use the contextual information in the recommendation process:

- *Pre-filtering*, where the contextual information is used to filter the data set before applying traditional recommendation algorithms.
- *Post-filtering*, where the contextual information is considered only in the final step of the process. So, contextual information is initially ignored and the ratings are predicted using any conventional 2D recommendation system, taking all the input data available (potential items to recommend) into account. Afterwards, the resulting set of recommendations is adjusted (contextualized) for each user by using contextual information.
- *Contextual modeling*, where the contextual information is used directly in the modeling technique.

So, the pre-filtering and post-filtering methods consider the context as an additional filtering step that can be applied to any traditional recommendation algorithm, either to restrict its input (pre-filtering) or its output (post-filtering). On the other hand, contextual modeling recommendation systems imply a radically different approach, as the contextual information directly affects the generation of the recommendation models.

In Section 6.1 we describe some relevant works performed in the field of CARS. However, we would like to emphasize that, despite the existing efforts, the design of flexible and generic architectures and frameworks to support an easy development of CARS has been relatively unexplored.

### 2.3. Basics of mobile context-aware recommendation systems (Mobile CARS)

The widespread availability of mobile devices, such as smartphones and portable computers, implies that the relevance of mobile computing scenarios is nowadays undeniable. This, in turn, demands new approaches for the development of recommendation systems that can handle and effectively exploit the data available in those environments. Thus, a recommendation system in a mobile computing scenario should rapidly obtain contextual information of the user, by using multiple sensors [10,11], accessing resources available in the Internet, etc.