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Expert Systems with Applications 29 (2005) 320–329

Expert Systems with Applications

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Modeling human behavior in user-adaptive systems: Recent advances using soft computing techniques

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Abstract

Adaptive Hypermedia systems are becoming more important in our everyday activities and users are expecting more intelligent services from them. The key element of a generic adaptive hypermedia system is the user model. Traditional machine learning techniques used to create user models are usually too rigid to capture the inherent uncertainty of human behavior. In this context, soft computing techniques can be used to handle and process human uncertainty and to simulate human decision-making. This paper examines how soft computing techniques, including fuzzy logic, neural networks, genetic algorithms, fuzzy clustering and neuro-fuzzy systems, have been used, alone or in combination with other machine learning techniques, for user modeling from 1999 to 2004. For each technique, its main applications, limitations and future directions for user modeling are presented. The paper also presents guidelines that show which soft computing techniques should be used according to the task implemented by the application.

Keywords: User modeling; Adaptive hypermedia; Soft computing; Machine learning; Data mining

1. Introduction

Adaptive Hypermedia (AH) can be defined as the technology that allows personalization for each individual user of a hypermedia application (Perkowitz & Etzioni, 2000).

The architecture of an AH system is usually divided in two parts: The server side and the client side. The server side generates the user models from a database containing the interactions of the users with the system and the personal data/preferences that each user has given to the system. These user models, in combination with a hypermedia database, are used by the 'Decision Making and Personalization Engine' module to identify user needs, decide on the types of adaptation to be performed and communicate them to an adaptive interface. Fig. 1 presents the architecture of a generic AH system.

The process of personalization in an AH system is defined as the ways in which information and services can be tailored to match the unique and specific needs of an individual or a community (Callan et al., 2001). Personalization is about building customer loyalty by building a meaningful one-to-one relationship; by understanding the needs of each individual and helping satisfy a goal that efficiently and knowledgeably addresses each individual's need in a given context (Riecken, 2000).

In this context, the user model is considered as a set of information structures designed to represent one or more of the following elements (Kobsa, 2001): (1) representation of assumptions about the knowledge, goals, plans preferences, tasks and/or abilities about one or more types of users; (2) representation of relevant common characteristics of users pertaining to specific user subgroups (stereotypes); (3) the classification of a user in one or more of these subgroups; (4) the recording of user behavior; (5) the formation of assumptions about the user based on the interaction history; and/or (6) the generalization of the interaction histories of many users into stereotypes (a stereotype is defined as a set of users that share a common behavior or interest).

The more information a user model has, the better the content and presentation will be personalized. A user model

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doi:10.1016/j.eswa.2005.04.005

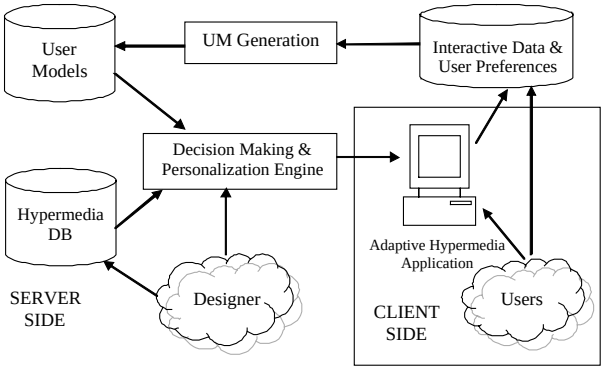

Fig. 1. Generic architecture of an adaptive hypermedia application.

is created through a User Modeling (UM) process in which unobservable information about a user is inferred from observable information from that user; for example, using the interactions with the system (Zukerman, Albrecht, & Nicholson, 1999). User models can be created using a user-guided approach, in which the models are directly created using the information provided by each user, or an automatic approach, in which the process of creating a user model is controlled by the system and is hidden from the user. This paper focuses on soft computing techniques to automate the acquisition and creation of user models in AH systems.

The problem of UM can be implemented using an automatic approach because a typical user exhibits patterns when accessing a hypermedia system and the set of interactions containing those patterns can be stored in a log database in the server. In this context, machine learning techniques can be applied to recognize regularities in user trails and to integrate them as part of the user model. Machine learning encompasses techniques where a machine acquires/learns knowledge from its previous experience (Witten & Frank, 1999). The output of a machine learning technique is a structural description of what has been learned that can be used to explain the original data and to make predictions. From this perspective, data mining and other machine learning techniques make it possible to automatically create user models for the implementation of AH services. Erinaki and Vazirgiannis (2003) and Pierrakos, Paliouras, Papatheodorou, and Spyropoulos (2003) present a review of how traditional data mining techniques can be applied to UM and the general architecture of such systems.

Nevertheless, traditional machine learning techniques have some limitations for modeling human behavior, mainly the lack of any reference to the inherent uncertainty that human decision-making has. This problem can be partially solved with the introduction of Soft Computing (SC) for UM. SC is an innovative approach to building computationally intelligent systems that differs from conventional (hard) computing in that it is tolerant of imprecision, uncertainty and partial truth. The guiding principle of soft computing is to exploit the tolerance for imprecision, uncertainty and partial truth to achieve tractability, robustness and low solution cost (Sinha, Gupta, & Zadeh, 2000). SC consists of several computing approaches, including neural networks, fuzzy set theory, approximate reasoning, and search methods, such as genetic and evolutionary algorithms (Jang, Sun, & Mizutani, 1997).

SC technologies provide an approximate solution to an ill-defined problem and can create user models in an environment, such as a hypermedia application, in which users are not willing to give feedback on their actions and/or designers are not able to fully define all possible interactions. Human interaction is a key component of any hypermedia application, which implies that the data available will usually be imprecise, incomplete and heterogeneous. In this context SC seems to be the appropriate paradigm to handle the uncertainty and fuzziness of the information available to create user models (Pal, Talwar, & Mitra, 2002). The elements that a user model captures (goals, plans, preferences, common characteristics of users) can exploit the ability of SC to mix different behaviors and to capture human decision processes in order to implement a system that is more flexible and sensible in relation to user interests. Different techniques provide different capabilities. For example, Fuzzy Logic provides a mechanism to mimic human decision-making that can be used to infer goals and plans; Neural Networks a flexible mechanism for the representation of common characteristics of a user and the definition of complex stereotypes; Fuzzy Clustering a mechanism in which a user can be part of more than one stereotype at the same time; and NeuroFuzzy systems a mechanism to capture and tune expert knowledge which can be used to obtain assumptions about the user. These techniques can be used to construct a user model by themselves or in combination with traditional machine learning techniques.

This paper will explore the development of user models using soft computing techniques from 1999 to 2004, focusing on the main journals and conferences for UM, mainly: User Modeling and User-Adapted Interaction journal; Expert Systems with Applications; International Conference on User Modeling; International Conference on AH; IEEE Transactions on Neural Networks; Workshop of Intelligent Techniques for Web Personalization (part of IJCAI-International Joint Conference of Artificial Intelligence); and International Workshop on Knowledge Discovery on the WEB (WEBKDD, part of the ACM SIGKDD International Conference on Knowledge Discovery and Data Mining). The paper's intentions are (1) to give an up-to-date view of Soft Computing techniques to UM and highlight their potential advantages and limitations, and (2) to give basic guidelines about which techniques can be useful for a given adaptive application.

The organization of the paper is as follows. The paper first gives a taxonomy of user models using two parameters: Granularity and task implemented. After that each SC technique is briefly introduced, giving also