GENERIC USER MODELING FOR ADAPTIVE ASSESSMENT SYSTEMS

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Abstract: Personalization is becoming a crucial factor in many areas of life including education. Currently, established e-learning systems mostly neglect the potential of user-specific adaptations such as optimized user orientation, sequencing or presentation by not considering an (appropriate) user model. But, a user model is the crucial factor how good and accurate the adaptations work. For that reason, this paper presents a generic approach for user modeling in the context of Adaptive Assessment Systems (AASs). The approach (1) enables recording skills and user characteristics, and the derivation of adaptable parameters; (2) allows incorporating additional parameters to determine specific properties and (3) ensures the interoperability through the use of established standards and specifications. In order to be generic and flexible in configuration, the overlay approach was used in combination with Bayesian networks. In addition, the interoperability of the approach is ensured through the use of the IMS LIP specification. Finally, the implementation of the approach is demonstrated in the AAS *askme!*. The work presented in this paper contributes to accurate characterizations of users, which in turn allows adequate levels of adaptability to reflect the real intelligence of an e-learning system.

1 INTRODUCTION

Today, centralized information systems offer the opportunity of data organization and representation. Based on intensive interactions between users and the system, in combination with raising user information recording, user-specific adaptations of the information systems are possible. Established information systems, especially e-learning systems, mostly neglect the potential of user-specific adaptations such as optimized user orientation, sequencing or presentation. The user model represents the basis for user orientation and therefore is an important and dependent factor how good and accurate the adaptations in the entire information system works.

For that reason, this paper presents a generic approach for user modeling in the context of Adaptive Assessment Systems (AASs). The approach (1) enables recording skills and user characteristics, and the derivation of adaptable parameters; (2) allows incorporating additional parameters to determine specific properties and (3) ensures the interoperability through the use of established standards and specification.

The work presented in this paper is part of an overall project aiming at implementing a new interactive and personalized assessment system (Saul and Wuttke, 2011b; Saul et al., 2011; Saul and Wuttke, 2011a).

The remainder of the paper is organized as follows: The second chapter gives an insight in related work in terms of user modeling. The third chapter states the shortcomings of existing approaches and provides a distinct categorization of user preferences. The fourth chapter proposes the generic approach for user modeling in the context of AASs and chapter five presents their implementation in the AAS *askme!*. Chapter six discusses these findings and concluding remarks and references complete the paper.

2 RELATED WORK

2.1 User Modeling in Adaptive Hypermedia Systems

The first steps towards considering user parameters for adaptation purposes were made by De Bra et al. in 1999 (De Bra et al., 1999) in the Adaptive Hypermedia Application Model (AHAM). Like the Dexter

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model (Halasz and Schwartz, 1994), AHAM focuses on the storage layer, the anchoring and the presentation specification, but further subdivides the storage layer into a domain model, a user model and a teaching model. The user model keeps track of how much the user knows about each of the concepts of the application domain (conceptualized by the domain model). Furthermore, it represents information about a specific user and therefore sets up the basic requirement for effects of adaptation. Brusilovsky and Millan (Brusilovsky and Millan, 2007) distinguishes between three different information types in user models namely:

- Application independent information (e.g., demographical data);
- Contextual information (e.g., user background);
- Information with a direct relation (e.g., through the domain model).

The first examples of systems with user models reach back to the early nineties with implementations of digital tutoring systems such as the Anatom-Tutor developed at the Fraunhofer Institute of Biomedical Engineering (IBMT) (Beaumont, 1995). Further developments were made by Weber and Brusilovsky with the ELM-ART system (Weber and Brusilovsky, 2001), an adaptive versatile system for web-based instruction. Finally, De Bra et al. created the AHA! system (De Bra et al., 2003) based on his assumptions about AHAM.

In general, two user modeling mechanisms can be distinguished (Brusilovsky and Millan, 2007):

- Stereotype-based user modeling.
- Feature-based user modeling.

In stereotype-based user modeling, the user is classified according to his/her knowledge level of the subject into different classes (e.g., novice, beginner, intermediate or advanced) and the system adapts the content or serves different content to users with different levels of knowledge. Examples of systems, which use this modeling mechanisms are Anatom-Tutor, AVANTI (Fink et al., 1996) and MetaDoc (Boyle and Encarnacion, 1994). In feature-based user modeling, the adaptation effect depends on the specific characteristic of each user. One of the most popular concepts in this domain is the overlay approach. The overlay approach arranges the specific characteristics of each user based on a predefined schema. According to (Brusilovsky and Millan, 2007), overlay concepts are especially useful for constructing complex data structures. Examples of systems, which make use of this modeling mechanisms are AHA!, ISIS-Tutor (Brusilovsky and Pesin, 1994) and HYPERFLEX (Brusilovsky, 1996).

2.2 Standards and Specification for User-modeling

There are mainly two standards and specifications, which are used to represent user information namely IMS LIP and IEEE LTSC PAPI.

The IMS Learner Information Package (LIP) specification[1] addresses interoperability between different systems. It holds, maintains and manages learner information in XML documents. Information is represented in 11 core data structures such as identification, goal, qualification, activity, competency, meaning skills, knowledge and abilities in the cognitive, affective, and psycho-motor domains, etc. However, IMS LIP makes no statement about the content structure in each category. Additionally, the specification records metadata such as timestamp, source and privacy information. Examples of applications include data recording and management of learning-related history or user goals and skills (Devedžić, 2006).

The IEEE LTSC Public and Private Information (PAPI) specification[2] is a standard to exchange learner data between different systems. It represents the learners' knowledge by specifying the learner-model. The learner information is divided into six groups namely learner contact information, learner relation information, learner security information, learner preferences information, learner performance information and learner portfolio information.

As there are disjoint attributes in both specifications (e.g., privacy and security issues), there are often combinations of elements of both specifications used (Lazarinis and Retalis, 2006).

3 PROBLEM STATEMENT

Summarized it can be stated that all systems described above use a user model for adaption, but the user information are mainly static and obtained explicitly. Moreover, existing approaches mainly focus on the entire learning process by providing educational hypermedia and often neglect the specific requirements the assessment part actually requires. This includes, for example, deriving and interpreting of user information from assessment results.

In addition, knowledge, background, interests and the personal characteristics of the user are important aspects that have to be taken into account in adaptivity decisions (Brusilovsky and Millan, 2007). A strict

[1] http://www.imsglobal.org/profiles/
[2] http://www.cen-ltso.net/Main.aspx?put=230

distinction between these aspects is not possible due to the mutual influence of the user properties. Therefore, the user preferences in this paper are divided into two categories namely *user knowledge* and *individual characteristics*.

3.1 User Knowledge

The principles of teaching consider an interactive operating learner, whose perception, interpretation and processing of information is based on his experience and progression. Therefore, the state of development of an individual is built on the entity of his perception, interpretation and processing of information abilities (Tulodziecki, 2000). The development of these cognitive abilities is seen as a process that can be measured by suitable means (e.g., tests, observation or self-assessments). Therefore, the user model is responsible for the recording of this learning process.

The user development occurs within an e-learning system by actively interacting with the system. User information, which are obtained during the learning process are in the focus of the user model. It can be distinguished between explicit and implicit information. Explicit information are gathered, for example, by assessments, whereas implicit information are gathered while the user interacts with the system. It is important to note that the majority of the information used for adapting the learning process is implicit. The interpretation of this information is one of the major problems a user model has to deal with.

3.2 Individual Characteristics

The second source for user information are the characteristics of the individual user. These characteristics can be divided into two different parts:

- General characteristics;
- Topic-specific characteristics.

General characteristics are, for example, the intrinsic or extrinsic motivation, cognition style or preferences of the user. They have a general impact to the learning process. In contrast, topic-specific characteristics, for example, the prior knowledge of the user are related to specific topics. It is important to note that both characteristics are mainly explicit. For that reason, recording, organizing and structuring of these information is another main problem a user model has to deal with.

4 PROPOSED SOLUTION

4.1 User Knowledge

To solve the problem of constructing (recording) the user-specific process of learning, the overlay approach proposed by (Brusilovsky and Millan, 2007) was chosen. An overlay model represents an individual user's knowledge as a subset of the domain model, which reflects the expert-level knowledge of the subject. Therefore, the model implies a close connection between the domain and the user model. The taxonomies of the domain model build the basic structure for the user model. To illustrate the approach, the domain model can be seen as an overlay of the user model as shown in Figure 1. As shown, the user model only contains a subset of all taxonomy elements available.

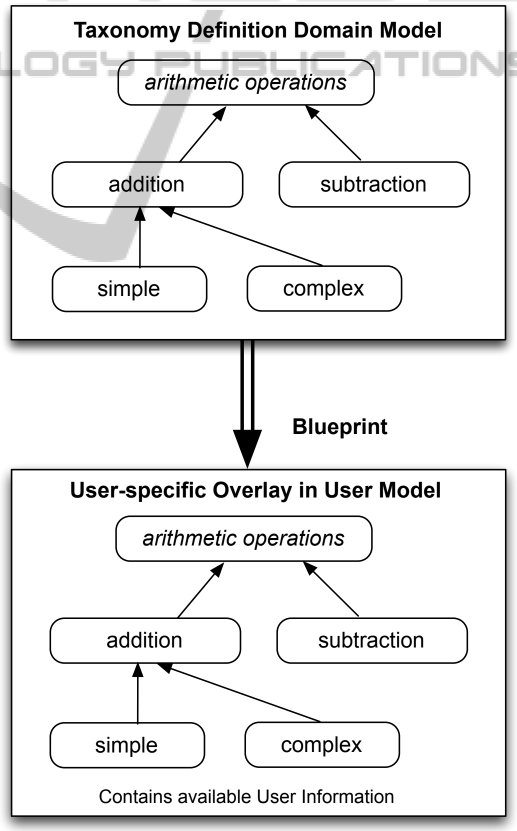

Figure 1: Overlay approach.

In addition to the recording of implicit user information, the interpretation of this information is an important point as well. To deal with this challenge, the Bayesian network approach (Jensen, 1996) was used. In general, Bayesian networks are acyclic graphs that consist of a set of variables. Between these variables a condition-dependent relation exists except for variables in the same level. These variables are condition-dependent (Millan and Perez-De-La-Cruz, 2002). Based on these relations, a probability calculation of each network node can be made. In this paper, the Bayesian network approach is used to determine user-specific probability of achievements for hierarchical taxonomies.

4.2 Individual Characteristics

To face the challenge of structuring and organizing individual user characteristics, an established standard or specification should be used. They play an important role as they enable interoperability across different systems. As mentioned in Section 2.2, there are mainly two standards and specifications for representing user information. In this paper, IMS LIP was chosen as data model for individual information, because problems were identified in IEEE LTSC PAPI in the lack of selectivity between the categories as well as in the limited expandability. IMS LIP provides a basic vocabulary for declaring user information and provides the opportunity of flexible and recursive structures. Arbitrary user information can be defined using 11 categories.

5 IMPLEMENTATION

The user model approach proposed in Chapter 4 was implemented in an AAS called *askme!* developed by the Fraunhofer Institute for Digital Media Technology (IDMT). *askme!* follows the AHAM reference model meaning that it consists of a user model, a domain model and an adaptation model, which closely work together. In addition, it consists of an adaptation engine, which performs the actual adaptation. For realizing adaptation during assessment, *askme!* uses the adaptive question technique (Pitkow and Recker, 1995). That means, it defines a dynamic sequence of questions, which allow selecting questions dynamically. Based on rules and the last response of the learner, appropriate questions are dynamically selected at runtime. *askme!* not only selects and presents questions individually, but also takes sophisticated feedback techniques and methods into account resulting in providing feedback that is appropriate for the learner's context, knowledge level, individual characteristics and preferences (Saul et al., 2010). Moreover, the sustainability of the questions and tests created in *askme!* is guaranteed by the conformance to the IMS QTI v2.1 specification[3]. The user model was implemented as a component in *askme!*. The relations to the other components are presented in Figure 2.

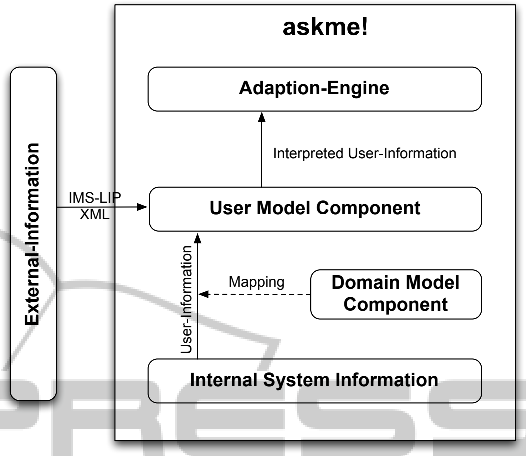

Figure 2: User model component relations.

As the system follows the Model-View-Controller (MVC) architectural pattern, the user model component is structured into several views and controllers for administration and input purposes. In order to accomplish the objectives of Chapter 3, the implementation combines different approaches.

Firstly, the overlay approach to represent the user knowledge was used. It was implemented in strong connection with the domain model. Due to that synergy, it was possible to store the user information in a single database table, which contains results from the assessment tests, the identifier for the user and the addressed domain. To satisfy the demand of the adaptation engine, the user model (in combination with domain information) is able to calculate the cumulated results of each domain element (including the children of each domain) for assessed questions. Furthermore, it is possible for the adaptation engine to request probabilities (p) that a user knows a specific concept of a domain. For that, the relations between the domain elements are used to calculate, in connection with the totally reached scores, the concept and user-specific probabilities (see Figure 3). The overlay approach was realized as a recursive algorithm, which calculates the scores and probabilities from the leafs of the domain (tree) to a given node. For that reason, the run-time of the algorithm strongly depends on the amount of child nodes given by the domain. Summarized it can be stated that the user model component provides different information to the adaption engine, which can be used in adaptation rules as static (e.g.,

[3]http://www.imsglobal.org/question/

scores) and dynamic (e.g., probabilities based on the domain definitions) conditions.

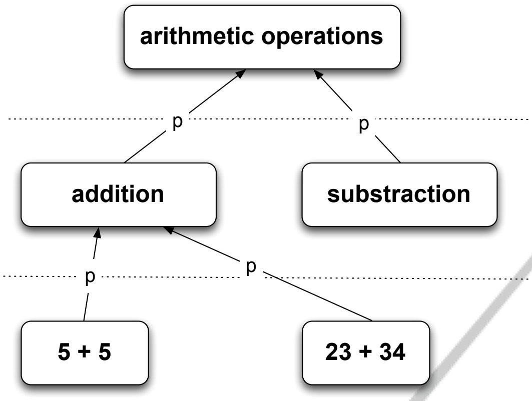

Figure 3: Bayesian network implementation.

Secondly, for recording of individual user characteristics, the IMS LIP specification was used as a framework to categorize the user characteristics. In order to face the recursive tree structure of IMS LIP, all categories were stored in a traversed database table. Additional data are stored in a dedicated database table and linked through a unique identifier of each individual characteristic. This enables defining own characteristics, which nevertheless are grouped in the 11 categories of IMS LIP. These characteristics are connected to specific users by a third database table (see Figure 4). In order to gather these information, different ways are possible, for example, explicit information can be given by the user himself or by an evaluation given by the tutor of the assessment system. The way of information gathering can be defined by the administration of the assessment system and depends especially on the concrete characteristic. Additionally, for interoperability purposes an IMS LIP import and export was implemented.

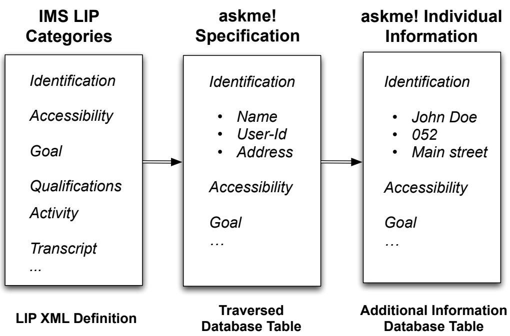

Figure 4: IMS LIP implementation.

6 DISCUSSION

The proposed approaches for user modeling in AASs also contain some critical aspects. First of all, the presented concept for recording user knowledge is questionable regarding the validity of the predictions. This issue concerns the user-specific probability calculation of domain elements, because of the dependence with the definition within the domain model. Each prediction of the user model is based on the probability parameters within the domain model. If the definition within these relations fails, the prediction about the users knowledge, made by the user model, will be invalid. To face this problem, it is important to evaluate the coherence of the relations within the domains. Such an evaluation will result in more predictable and also more precise user models.

The second aspect concerns the IMS LIP specification. The loose definition within the data model does not provide only advantages. It can also cause incompatibilities and problems with the differentiation of the individual characteristics. Due to the rough definition within the 11 categories, overlapping dimensions are possible. Another issue concerns the missing standardization of IMS LIP. As long as there is no consensus within the e-learning community, there will be no fixed definition of important individual characteristics. But, IMS LIP has the potential to become a de facto standard and nevertheless has strong synergies with the well known IMS QTI specification.

Finally, there is a general problem of user modeling in information systems. As described by Bloom et al. (Bloom et al., 1956) and Anderson and Krathwohl (Anderson and Krathwohl, 2001), the process of learning (and of course concerning the users knowledge) contains more cognitive process dimensions than remembering and understanding. The challenge within systems in e-learning context (especially for the user model) is to record advances thinking skills. Referring to Wuttke et al. (Wuttke et al., 2008), it is not really possible to measure these skills with traditional assessment techniques such as multiple-choice questions. Therefore, more complex techniques like interactive and immersive tools have to be integrated and used in the assessment process. Until now, these applications are developed stand-alone with no relation to learning or assessment systems. However, the measurements of aggregated data could be beneficial to record advanced thinking skills. Standards like HR-XML[4] already demonstrate how these interactive applications could transfer their data to build more detailed and precise user models.

[4] http://www.hr-xml.org/

7 CONCLUSIONS AND FUTURE WORK

User models provide necessary data to adapt digital information systems to the individual user. The approach proposed in this paper especially concerns user models for AASs. In this context, basic assumptions were made to create user-specific models that support user-specific adaptations. As a result, the highly efficient overlay approach in combination with Bayesian networks and the inclusion of the IMS LIP specification were presented. The presented approach is highly generic and flexible in configuration. Furthermore, critical aspects such as the validation and interpretation problem of user information were discussed.

Future work of the institution of the main authors will address the validation of the model by performing a comprehensive evaluation. It will point out the educational benefits (e.g., how precise are the generated user information) of the approach and their implementation.

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