A Survey of Context-Aware Cross-Digital Library Personalization

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Abstract. The constant interaction of users with different Digital Libraries (DLs) and the subsequent scattering of user information across them raise the need not only for Digital Library interoperability but also for cross-Digital Library personalization. The latter calls for sharing and combining of user-information across different DL systems so that a DL system may take advantage of data from others. To achieve this goal, DL systems should be able to maintain compliant and interoperable user models and profiles that enable propagation and reconciliation of user information across different DLs. In this paper, we motivate the need for cross-Digital Library personalization, we define and examine user model, profile, and context interoperability, and we survey and discuss existing user model interoperability approaches.

Keywords: cross-Digital Library personalization, user model interoperability, user profile, user context, interoperability approaches.

1 Introduction

Whether digitized or born digital, the information found in Digital Libraries (DLs) is growing at an unprecedented rate making it difficult for individuals to identify relevant items in a reasonable amount of time. Furthermore, the new generation of DLs is more heterogeneous than before regarding content diversity and user-community variety. Hence, DLs increasingly need to be more effective at providing information that is tailored to a person's preferences, interests, knowledge, skills, etc. For such personalization to be successful and result in different system behaviors to different users, a DL system needs to provide adequate representation of a user, conforming to a proper *user model* supported

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by the system. Each individual instantiation of the user model is called a *user profile*. It is apparent that the profile of a user is also influenced by the *user context*, which is all information that characterizes the environment of a user, resulting in differences in preferences and actions during different interactions of the same user with a DL. Hence, *context models* are necessary as well.

Nowadays, users interact with different DL systems on a regular basis and update their profiles stored at these systems. These distributed and heterogeneous profiles constitute a valuable source of information for DL systems to "understand"their users better and improve their personalization and adaptation services. This user information, however, is not easily transferable from one system to another. To achieve cross-Digital Library personalization, DL systems should go well beyond the traditional techniques for their interoperability (or any other Information System, for that matter), which is usually confined to sharing and mapping of primary content and metadata; they should take into account the precise nature of user profiles and proceed with a new theory for handling "user interoperability". In addition, they should prevent users from entering the same information into every system, but reuse each other's profiles freely.

The goal of achieving cross-Digital Library personalization in a collaborative and interoperable setting raises several issues related to different user models that DLs may use, different user profile characteristics captured in different DLs, or even different aspects of the user context. The following example helps to illustrate the above. Consider two different DLs that aim to interoperate. DL A is a historical DL that typically contains multimedia documents illustrating the history of European countries. Each multimedia document is composed of a text describing the history of a country, a video showing important monuments, and several audio files with each country's traditional music. DL B is a research DL, owned by a research institution, and stores advanced research results. Each DL has its own set of users (user profiles), which may nevertheless, overlap with the other set. The two DLs should communicate in such a way that their users can access them as if they were a single DL. To achieve this goal, the systems' user models should be interoperable, which is a major challenge: DL A uses a simplified user model, capturing basic characteristics of a user, without providing significant personalization capabilities; on the contrary, DL B supports an enriched user model, records several user preferences, and offers advanced personalization techniques. How can a user of one DL be transferred to the other? Is there a natural mapping between the two different user models? Is it possible for user characteristics captured in both DLs to be consolidated so that a user can have a personalized usage experience in both systems? Are there any privacy issues?

This survey paper describes relevant state-of-the-art approaches that attempt to address these questions. Approaches for user model, profile, and context interoperability have been developed in recent years for general adaptive web-based systems such as recommender and educational systems. Nevertheless, no much effort has been devoted to the creation of relevant solutions for DLs. As cross-Digital Library personalization evolves in a matter of major importance for future interoperable DLs, it influences its underlying requirements such as user model, profile, and context interoperability to gain the relevant attention. For this reason, the six approaches that will be described in following sections, which were not explicitly developed for DL systems, may have the dynamics to be regarded as suitable for resolving DL-related user interoperability issues. The remainder of this paper is structured in the following way. Section 2 defines user modeling, user profiling, and user context as well as the concept of interoperability for each one, at both the semantic and syntactic levels and, finally, introduces some privacy concerns. Section 3 presents the state-of-the-art approaches related to user model interoperability and then elaborates further on those that are applicable to user profile and user context interoperability. Section 4 discusses the advantages and disadvantages of the approaches identified. Finally, Section 5 concludes the paper and introduces some directions for future research.

2 User Interoperability

As it was mentioned in the previous section, adequate user modeling is important for personalization. Respectively, appropriate *user model interoperability* is essential for cross-Digital Library personalization.

We can define user modeling as the process of capturing all the fundamental information about DL users in order for the system to be able to provide personalized information to different users. We can distinguish user modeling from user profiling by defining user profiling as the process of collecting information about a user in order to generate the user's profile, depending on the current user model. In general, a user model should be rich enough to allow different access to the content and the functionalities provided by the system, to maintain the explicit or implicit preferences affecting the results of the user operations, and to differentiate based on the context of the user. Attributes of the user that may be reflected in a DL are user credentials, demographics, access rights, preferences, interests, background, level of maturity and expertise, etc. Up to now, however, there is no generally accepted user model that may be used in every Digital Library application and ensure that a profile created within a certain DL may be moved effortlessly to another. Thus, interoperability in terms of user modeling refers to the ability of DL systems to support compliant and interoperable user models that enable the propagation of user information across different DLs.

Having a common model or a way to move a user profile from one DL to another is not enough. On one hand, there is the issue of user rights and how they are propagated from one DL to the other. On the other, there is the issue of reconciliation of different and, in some cases, even conflicting preferences or user profile characteristics. It becomes apparent, that another type of interoperability is also needed. Thus, interoperability in terms of user profiling refers to the ability of DL systems to support mechanisms of reconciliation of user profile characteristics.

Moreover, there are "external" factors to the user model related to the context of a user that may affect the profile and result in differences in preferences and actions when a user interacts with a DL. The issue of user context is an issue that has not been fully explored and defined but is very much related to interoperability and user modeling. Context may include the user "situation", position, time, role, company of other users, etc. Thus, identifying the relation between user model and user context, as well as revealing where the user model ends and the context begins form important issues for further investigation. Interoperability in terms of user context refers to the ability of DL systems to support compliant context descriptions and interpret user information in a concrete way given the same context.

The interoperability of user models, profiles, and context should be achieved in the *syntactic* and *semantic* level. Syntactic interoperability refers to the capability of different DL systems to interpret the syntax of the delivered user model/profile/context in the same way. Semantic interoperability is concerned with ensuring that the precise meaning of exchanged user model/profile/context characteristics is understandable by any other system.

Finally, privacy issues are very critical for cross-DL personalization [38]. In the context of cross-DL personalization, that requires user models to be shared across systems, privacy is not only related to acquisition of permission from users to collect and use their data, but it is also related to obtainment of users' explicit consent before transferring user information to other systems. Privacy concerns associated with the latter include a) the systems that can access user data, b) the part of the user profile that can be made available to other systems, c) the time period the user data are retained, etc.

In the following section, a number of approaches that resolve the identified interoperability issues are described unveiling also the realization of syntactic and semantic interoperability.

3 User Model Interoperability Approaches

General User Modeling Systems (GUMS) proposed by Kass and Finnin [19] offer various user modeling services. However, they have seen limited use [20]. Apart from these user modeling approaches, there are also some standardization efforts of user model relevant aspects. The IEEE Public and Private Information (PAPI) specification [10] was created to represent student records. The IMS Learner Information Package (LIP) specification [11] provides a model that represents user attributes required for recording and handling learning history, goals, and achievements. IMS and PAPI are generic and well known standards, but suffer from some disadvantages. They are not conceptually extensible and do not represent dynamic user attributes, like preferences and interests. The work of Orwant called "Doppelgänger" [30] focused mainly on the collection and distribution of user information and the use of several learning methods. In this approach, the basic problem of sharing user data had already been identified.

Recent advances in user model interoperability reveal three basic approaches that focus on achieving syntactic and semantic interoperability of user models: a shared-format approach, a conversion approach, and an intermediate approach.

The shared-format approach enforces the use of a shared syntax and semantics to represent user models. On the other hand, the conversion approach, as does not use a shared representation for user models, employs appropriate methods to transform the syntax and semantics of the user model used in one system into those of another system. Finally, an intermediate approach integrates the advantages of both approaches to enable adaptability in describing user models and to offer a mapping of user information from one system to another [7].

3.1 Shared-Format Approach

The use of a shared-format for the representation of user models has an obvious advantage. This is the acquisition by a DL system of user attributes discovered by other DL systems. In this way, the DL system may use the existing data for personalization without the user being obliged to input them again.

In the field of music information retrieval, Chai and Vercoe [9] proposed the representation of user models in a standardized format. Their User Model for Information Retrieval Language (UMIRL) uses the XML syntax in order to represent different user models that can be shared across systems. Another example from this field is the MPEG-21 standard [27] that defines an open framework for multimedia applications. Users are identified by their relationship to other users and every user may have specific rights and duties depending on his interaction with other users.

The user modeling community focuses on ontology-based approaches as the basis for the shared-format approach in order to achieve user model interoperability. Ontology-based approaches have several advantages that originate from the principles of this formalism. The ontological representation of user attributes allows the deduction of additional user attributes based on ontology relations, conditions, and restrictions. The use of an ontology-based user model increases the potential for user attributes to be shared among DL systems. Approaches that belong to this category and will be described in detail include the General User Model Ontology, the Unified User Context Model, and the Ontology based User Model.

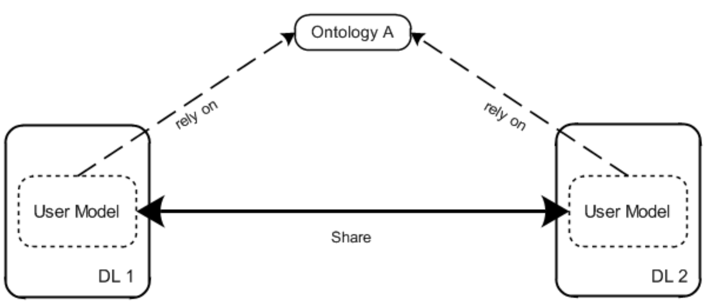

Fig. 1. Shared-Format Approach

General User Model Ontology. Heckmann et al. [13], [14], [17] proposed the General User Model Ontology (GUMO) in order to manage the syntactic and semantic variations between user modeling systems. The General User Model Ontology is based on OWL and is used for modeling user attributes and their interrelationships. The authors selected the user's attributes that are modeled in user-adaptive systems as well as user's interests and preferences. The construction of the user model ontology GUMO was based on the thought to divide the description of user model attributes into three elements: auxiliary - predicate - range. This description is called a *situational statement*. For example, the interests of a user in music could be described in the following way: auxiliary=*hasInterest*, predicate=*music*, and range=*low-medium-high*. The situational statement apart from the main information contains also contextual information and privacy preferences [12]. The privacy attributes (key, owner, access, purpose, retention) enable controlled propagation of sensitive information. Owner's intended privacy settings accompany the statement itself when it is exchanged among systems. User profile interoperability issues are handled by applying conflict resolution strategies among situational statements [14]. The authors also introduced the u2m.org user model service that is an application-independent server for maintaining and retrieving user profiles and for exchanging these profiles between different applications. A key advantage is that interoperability between distributed user-adaptive and context-aware systems is achieved because the semantics for all user model and context attributes are mapped to the general user model ontology GUMO [16].

The characteristics and attributes of GUMO are applied in the user model exchange language called User Modeling Markup Language, UserML [15], which promotes the exchange of user models across systems. The GUMO approach has been used for the representation of museum visitor's models in the Mobile Museums Guide [21] and it has been tested in a Positioning Service [5] and an Alarm Manager application [4].

The Unified User Context Model. Niederee et al. [25], [28] introduced a Unified User Context Model (UUCM) that can be used for modeling attributes of the user and his environment, i.e., the user context. Their proposal identifies two levels for the unified user context model, the abstract and the concrete level. The *abstract* level specifies the principal components of the UUCM that are: user context, user model attributes, main characteristics for attributes representation, and user model dimensions. For the cross-system personalization, this level specifies a shared ontology and all systems depend on this model. The *concrete* level defines a group of UUCM dimensions and attributes that include not only users' interests, but also tasks and relations to other entities and relevant user communities. Different attributes are modeled with the use of name/value pair. In this way, each attribute of the user context model is captured and new attributes can be easily added. Each UUCM attribute is represented by the following features: attribute name, attribute qualifier, attribute value, value qualifier, value probability, and attribute dimension. Moreover, the four UUCM dimensions selected for the context model are the Cognitive Pattern, the Task, the Relationship, and the Environment. Finally, relevant subsets of the user context model are defined that are called user's working contexts and are used to distinguish the different roles that the user can play.

The UUCM defines the structure of the user context profile that can be used not only to express a user in a system but also as an intermediate type for the exchange of user profiles between different systems.

In the Niederee et al. approach for cross-system personalization, a context passport based on the UUCM is used to accompany the user when moves from a system to another. The context passport is a concise encapsulation of the user's current context profile and also includes the activities chosen by the user to be executed in order to complete the allocated tasks. When the user performs an activity, the respective part of the context passport is selected and used in order to better support the requirements of the user.

Ontology Based User Model. Razmerita et al. [31] proposed the Ontology based User Model (OntobUM) that is a generic ontology-based user modeling architecture developed for a Knowledge Management System (KMS). OntobUM was created within the Ontologging project [29] that aimed to implement the next generation of KMSs based on three technologies: ontologies, software agents, and user modeling.

OntobUM combines three different ontologies: the *user ontology* that expresses the users, the *domain ontology* that specifies the relationships between the different applications, and the *log ontology* that determines the semantics of user-application interaction. Semantic Web technologies were employed for the implementation of the user ontology, and the structure of this ontology was based on extended IMS LIP specifications.

The complete user model for a user is composed of an explicit part specified by the user via the user profile editor and by an implicit part retained by services. The explicit part of the user model encompasses attributes such as identity, email, address, abilities, cognitive style, and preferences. The implicit part is connected to experiences related to the use of the system. For this reason, the authors have enhanced the IMS LIP groupings by introducing the Behavior notion. The Behavior notion describes attributes of users interacting with a KMS such as level of activity, type of activity, and level of knowledge sharing. Based on users' activity in the system, OntobUM categorizes the users into three classes: readers, writers, or lurkers. These classes are properties of the type of activity attribute. The level of activity includes four characteristics that can be related to the user: very active, active, passive, or inactive. The level of knowledge sharing captures the level of acceptance of knowledge sharing methods. Based on the above attributes, the system is able to provide feedback and virtual rewards.

3.2 Conversion Approach

It is apparent that by adopting a shared format approach by DL systems, there are no syntactic or semantic heterogeneity issues to be solved. All the systems use the shared unified model that is easily exchangeable and interpretable. Nevertheless, the DL systems that exist nowadays are very heterogeneous and dynamic.

This makes it impractical, and in some cases even impossible, to use a shared user model and to enforce DL systems to adhere to a shared vocabulary. There is another approach, the conversion approach that does not compel DLs to use a unified model but defines appropriate mechanisms in order to transform the syntax and semantics of the user model attributes in one system into those used in another system.

An example of this approach is given in Stewart et al. [33], where the interoperability of user models between two different Adaptive Educational Hypermedia systems, MOT and WHURLE, is done via a one-to-one conversion. Firstly, the identification of a set of common attributes between the user models of the two systems is performed and then the conversion is completed through a peer-to-peer interaction. A more general approach is the Mediation of User Models approach proposed by Berkovsky et al. [3] that will be analyzed in the following section.

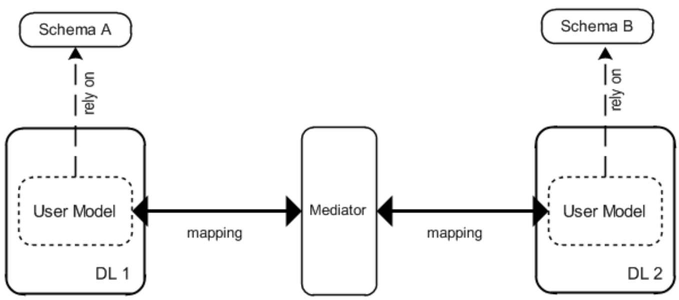

Fig. 2. Conversion Approach

Mediation of User Models. Berkovsky et al. [3] introduced in their work a generic framework for user model mediation. Mediation of user models is a process of transferring and incorporating the user model information collected by other systems for the goal of a particular recommendation proposition. This work also focuses on resolving the heterogeneity of the available user model information, as pays particular attention on the resolution of inconsistencies and conflicts among the information obtained from various systems.

A user model is represented in a three-dimensional space. The two generalized dimensions of this representation are *users* and *items*. These dimensions are called generalized because they may be described by sets of specific attributes. In order to facilitate provision of context-aware recommendation, the above two dimensions are extended by a third general dimension, indicating various contextual conditions and attributes that may be considered by the recommender system.

The mediation process includes a *target* recommender system that is the system requested to provide personalized recommendations to the user and one or more *remote* recommender systems that may provide pertinent user model data (past experiences) to the target recommender system.

The authors have defined four major types of mediation. The first type is called *cross-representation mediation* and is performed between experiences having the required values of all three attributes (user, item, context). The other three mediation types are mentioned as *cross-dimension mediations*. They are performed over the experiences having the required values of two attributes and a different value of one attribute. This means that the values of two out of three attributes are fixed and the mediation is conducted across the third attribute. Three types of cross-dimension mediations are distinguished: (a) *cross-user mediation*, where the values of item and context attributes are fixed and the user in the experiences is allowed to be revised; (b) *cross-item mediation*, where the values of user and context attributes are fixed and the item in the experiences is allowed to be revised; and (c) *cross-context mediation*, where the values of user and item attributes are fixed and the context in the experiences is allowed to be revised.

The authors resulted in the conclusion that mediation techniques may enhance the quality of the personalized recommendations and the performance of systems only in particular conditions. These conditions include the type of mediated data, the availability of user modeling information in the source and target systems, and many other factors. Therefore, the decision regarding applying the mediation should be taken only after a comprehensive analysis of these aspects.

The issue of user model mediation was studied within the SharedLife project [37] and the Passepartout project [1]. Furthermore, Berkovsky et al. [2] implemented user model mediation between a trip-planning system [32] and a personalized museum visitor's guide [23].

3.3 Intermediate Approach

The intermediate approach combines the benefits of the shared-format approach and the conversion approach. Specifically, the systems may use their own user models but they should provide a sharable part of their models in order to be exchanged with other systems. Then, a mediation method can be applied in order to provide a mapping of user information from one system to another. Concrete approaches that fall in this category are the Generic User model Component and the Framework for User Model Interoperability that will be presented in detail in the following sections.

Generic User Model Component. Van der Sluijs et al. [35], [36] introduced the Generic User model Component (GUC) that applies Semantic Web technologies to retain user models and to share user profiles between applications. Applications have the ability to store their user models in the GUC's application schema repository and to use GUC in order to upload user profiles that are valid only in a certain context. If the user uses the application in another context, another profile is stored. GUC employs the Shared User Model (S-UM), which includes the most used attributes within the domain, as a mean of user model exchange between various applications. S-UM can be used as a mediator for the exchange of user data between applications by creating a mapping to and from every application and S-UM.

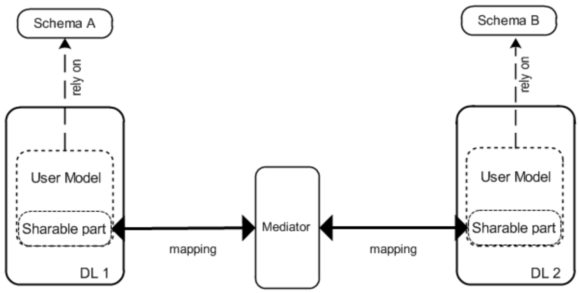

Fig. 3. Intermediate Approach

A schema mapping from a user model X to a user model Y includes a specification of how all attributes in user model X are mapped to corresponding attributes in Y. Schema mappings are produced by the GUC mapping component that needs the source and the target user model, say X and Y respectively. The mappings are created based on the similarities between two input user models and are expressed in the language SWRL. The mapping between user model X and user model Y has to be constructed only once and, therefore, can be created by a human designer. Irrespectively of the algorithm used for the schema mapping, the result must be examined and possibly be edited by hand before it can be used, because semantic structures may not be interchangeable on instance level.

The Generic User model Component deals also with the issue of data reconciliation when it is used for exchanging user data between applications. An application can ask for a specific user profile that is called a User Application View (UAV). A UAV of an application's user model can be translated into a (partial) UAV of another application's user model. Data reconciliation is supported by applying the OWL and SWRL techniques. For each application, rules should be defined to indicate how to reconcile data in the case of a conflict. Data reconciliation rules help to specify what to do if a value in the converted UAV already exists in the UAV that it should be incorporated. Possible approaches include the concatenation of the value with the current one, or the replacement of the current value, or the use of a given formula in order for a decision to be taken. Finally, GUC is able to apply privacy policies by allowing each user to have access to all data stored about him and control which applications may get access to which data.

Related research on Generic User model Component was conducted within the Alter-Ego project [34] and the IST MobiLife project [26].

A Framework for User Model Interoperability. According to Carmagnola's approach [7] systems do not require sharing a user model, but each system may use the user model that wish. Nevertheless, her approach uses RDF in order to assure the syntactic interoperability of the exchanged semantic-enriched user data. In her framework, the interoperability procedure takes place when an application, called *receiver Rc*, may want to obtain data about a user from other systems, called *providers Pr's*. In order for a provider system to participate in the interoperability procedure, it should preserve a shareable user model that includes those parts of the user model that can be shared with other systems as RDF statements. Every statement represents the user model information that can be shared with other systems. A statement can be broken into four parts: a subject, a property, an object, and a value.

When a receiver system *Rc* needs to collect user model data from other systems, it begins the interoperability procedure first by retrieving the shareable user models of provider systems *Pr's* the user interacts with and then by searching for the particular user model data into those user models. Subsequently, receiver *Rc* obtains from a specific provider *Pr* the entire group of the statements that belong to user's shareable model. In order to measure the semantic similarity among the statements, each statement is divided into Object and Property. Then, the Object Similarity Algorithm is used to determine the similarity between the objects and the Property Similarity Algorithm is used to calculate the similarity between the properties. To compare the semantics of the objects in provider's and receiver's statements the author employs the Word Sense Disambiguation Theory which assumes that two terms are semantically interchangeable if their micro-contexts are interchangeable [18]. The micro-context of a term can be defined by dependence on two main sources of information: a) the information incorporated in the text or discourse in which the term appears, b) external knowledge sources, including lexical, encyclopaedic, etc.

Assuming the user is the same among two statements belonging to provider *Pr* and receiver *Rc* and the Osm Algorithm results that the objects in the specific statements are similar, it has also to be examined if the properties in those statements are similar. The Psm algorithm determines the similarity among the properties using the Levenshtein distance [24] that allocates a unit cost to all edit operations needed to transform one string into another.

Finally, the similarity measure between provider's *Pr* and receiver's *Rc* statements is obtained as the average of Osm and Psm results. The highest similarity measure between a provider's statement and the receiver's statement gives the highest relevance for the receiver *Rc*.

Carmagnola's research on user model interoperability was part of her doctoral thesis [6] that also contained a mechanism for the identification of the user whose information is shared across systems [8].

4 Discussion of Approaches

The approaches described in the previous section have been proposed as general user model interoperability solutions. They have not been specifically tailored to achieve user model interoperability in Digital Libraries. The six approaches presented in this work have the dynamics to be used for user interoperability in DLs; however they may have several weaknesses as they do not take into account the special needs and characteristics of the DL community.

Table 1. Comparison of Interoperability Approaches

	User Model Interop.	User Profile Interop.	User Context Interop.	Privacy Concerns
GUMO	+	+	+	+
UUCM	+	-	+	-
OntobUM	+	-	-	-
Mediation of User Models	+	+	+	-
GUC	+	+	+	+
Framework for UM Interop.	+	-	-	+

The above comparative table summarizes the six approaches, described in previous sections, in terms of user model, profile, and context interoperability and privacy concerns. The sign (+) indicates that the approach covers the specific requirement whereas the sign (-) indicates that the requirement is not captured. The General User Model Ontology (GUMO), the Unified User Context Model (UUCM), and the Ontology based User Model (OntobUM) that belong to the shared-format approach are suitable for systems that may easily agree to share a common user model format. In the case of several DLs interoperating, there may be special circumstances that do not allow a common model to be generally put into practice. Moreover, the GUMO approach pays attention to privacy by defining privacy attributes, whereas UUCM and OntobUM do not deal with this issue.

The approach that would probably be better suited for interoperable DLs should contain a form of conversion of one user model to another. An important approach is the Mediation of User Models. This approach, however, does not take into account the variety of user attributes the systems have collected about the user [22]. Also, this approach does not handle privacy issues. Another promising solutions is the first intermediate approach, GUC, because not only it provides a schema mapping among different user models, but also, focuses on instance mapping among different user characteristics captured in different systems. The problem is that the mapping requires additional human effort and may not always be feasible.

The last approach that is presented in this work performs similarity checking among the various user model statements in order to overcome the semantic heterogeneity of different user models. Its weakness is that it does not provide a solution for the examination of the differences of the actual values captured in different systems.

5 Conclusion

In this paper we introduced the need for cross-Digital Library personalization by defining and analyzing user model, profile, and context interoperability. Then, we described six important user model interoperability approaches. Relevant description was provided for those approaches that focus also on user profile and context interoperability as well as on privacy issues.

The conclusion that can be drawn from our investigation is that little work has been done on achieving user model interoperability across different systems. Moreover, there is a need for additional research on this issue in the Digital Library community in order to achieve cross-Digital Library personalization. New research directions are emerging that need not only to focus on user model interoperability, but also on reconciliation or consolidation of different user attributes as well as on propagation of access rights across different DL systems. Finally, more intensive efforts are needed to cope with the challenging issue of user context and its correlations with the user profile.

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