Modeling Users and Context in Digital Libraries: Interoperability Issues

Ana Nika[1], Tiziana Catarci[2], Akrivi Katifori[1], Georgia Koutrika[3], Natalia Manola[1], Andreas Nürnberger[4], and Manfred Thaller[5]

[1] University of Athens, Athens, Greece
{a.nika, vivi, natalia}@di.uoa.gr
[2] Sapienza University of Rome, Rome, Italy
catarci@dis.uniroma1.it
[3] Stanford University, California, USA
koutrika@stanford.edu
[4] Otto-von-Guericke University Magdeburg, Magdeburg, Germany
andreas.nuernberger@ovgu.de
[5] University of Cologne, Cologne, Germany
manfred.thaller@uni-koeln.de

Abstract. The modeling of user characteristics is an important mechanism for the support and enhancement of personalization in Digital Libraries (DLs). Contextual information is sometimes considered in the literature as part of the user model, although it in fact influences user-DL interaction. However, context modeling and user modeling are strongly interrelated. Similar methods are employed for the representation of user context and user model and the use of ontologies constitutes a promising approach for such a representation because they facilitate the sharing of information and reinforce interoperability. In this paper, we define the user model and user context for Digital Libraries, we examine identified context dimensions as well as context-independent and context-dependent user model attributes, and we propose a Shareable User and Context Model Ontology (SUCMO) for user representation in DLs that may be used to augment personalization and achieve user interoperability. Furthermore, we present our implemented interoperability process that includes ontology mapping, generation of the shareable user profile, information exchange, and reconciliation rules and we conclude our paper by discussing future research directions.

Keywords: user context dimensions, user model attributes, ontology, user interoperability

1 Introduction

Digital Libraries (DLs) are heterogeneous systems that provide different functionalities. So far, there is no accepted definition of what a Digital Library is. According to the Digital Library Reference Model [6] a DL is *a potentially virtual organization that comprehensively collects, manages and preserves for the* *long depth of time rich digital content, and offers to its targeted user communities specialized functionality on that content, of defined quality and according to comprehensive codified policies.* This general definition affects also the user attributes that need to be captured by the DL in order to offer a personalized experience to different users. Until now, there is no generally accepted user model for DLs and the Reference Model does not specify what user characteristics are significant to be reflected in such a user model. Furthermore, contextual information is of particular importance for Digital Libraries because it influences user interaction with the DL.

In the last years, much research has been devoted to the understanding, definition, and modeling of the notion of context. Context has been examined for general purpose systems as well as specific systems such as mobile and sensor networks where context changes rapidly. As far as the authors are aware, there has been no comprehensive study of the notion of user context in the DL field.

In this paper, our aim is to propose definitions for the user model and the user context for DLs as well as to provide a clear distinction between user model attributes and user context dimensions. Context-aware DLs will support personalized access to users by providing the right information and services. It is evident that by identifying and obtaining relevant context, DLs may adapt themselves to better suit users needs. Nevertheless, user context modeling is conceptually different from modeling of user attributes. Some context dimensions can hardly be considered information about the user, but, in the literature, they are often captured and included in user models. Similarly, user attributes are frequently regarded as part of different context models. However, context modeling and user modeling are strongly interrelated. Not only similar methods are used for the representation of user context and user model, but also context dimensions influence specific user attributes such as preferences and interests that will be named context-dependent attributes in following sections. For this reason, we investigate and propose the use of a Shareable User and Context Model Ontology (SUCMO) for the representation of the user model and the contextual information that affect user's behavior because ontologies facilitate the sharing of information and enhance interoperability.

Nowadays, users interact with different Digital Libraries and their information is scattered throughout them. This raises the need for personalization not to be limited to one system but to be applied across DLs. Cross-Digital Library personalization means sharing and combining user information across different DL systems so that a DL system may take advantage of data from others. This user information, however, is not easily transferable from one system to another. To achieve cross-Digital Library personalization, DL systems should take into account the precise nature of user profiles and proceed with a new theory for handling user model and context interoperability. For this reason, we propose the use of our ontology for the support of user model and context interoperability across DLs and we present our implemented interoperability process.

The remainder of this paper is structured as follows. Section 2 provides related work on the definition and modeling of context, a review of the current user model representation approaches as well as an investigation of user model and context interoperability approaches. Section 3 introduces our definitions for user model and user context and the identified context dimensions as well as context-independent and context-dependent user model attributes. Section 4 proposes the use of a Shareable User and Context Model Ontology for the user representation in DLs and discusses the advantages of such an approach. Section 5 presents our interoperability process for achieving user model and context interoperability with the use of the proposed ontology. Finally, Section 6 concludes the paper and introduces future research directions.

2 Related work

2.1 Context Dimensions and Modeling

In recent years, researchers have attempted to better understand context by creating different context definitions. Schilit et al. [24] were among the first that focused their attention on the definition of context. They described it as location, identities of nearby people, objects, and changes to those objects. Benerecetti et al. [1] introduced two dimensions of context: physical context and cultural context. Physical context is a set of environmental characteristics while cultural context includes user information, user preferences, background beliefs, etc. Lieberman and Selker [17] defined context as the state of the user, of the physical environment, and of the computational environment as well as the history of user-computer-environment interaction. Lucas [18] distinguished three dimensions of contextual information: physical context, device context, and information context. Device context includes characteristics of the device itself while information context is related to the knowledge about information objects whose existence and identity are distinct from those of the devices that process them. Brown et al. [4] defined context as location, identities of the people around the user, the time of day, season, temperature, etc. Ryan et al. [23] included in their work four user context dimensions: user's location, environment, identity, and time. Nowadays, Dey's and Abowd's definition of context [10] is considered as the most accepted one. They defined context as follows: *"Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves."*

Apart from the aforementioned attempts to define context, much research has been devoted to the area of context modeling. A well designed context model constitutes a critical step for the development of context-aware systems. Several approaches have been proposed for the representation of context. Strang and Linnhoff-Popien [25] performed a comparative study of different context modeling approaches. The authors identified six categories for context representation: a) Key-value models, b) Markup scheme models, c) Graphical models, d) Object oriented models, e) Logic-based models, and f) Ontology-based models. They arrived at the conclusion that the most promising context modeling method can be found in the ontology category [26] because it provides a good sharing of information with common semantics.

2.2 User Model Attributes and Representation Approaches

User models and the attributes captured in these models have been studied extensively. The number of features represented in a user model depends to a large extent on the kind of adaptation that the respective system wishes to provide. Rich [22] proposed a three-dimensional space of user models: 1) canonical vs. collection of individual user models, 2) explicit vs. implicit user models, and 3) long-term vs. short-term user models. Brusilovsky and Millán [5] collected the five most popular and useful user characteristics: the user's knowledge, interests, goals, background, and individual traits. Preferences [15] and interests [28] are considered as very important attributes for most systems that incorporate user profiles. Tazari et al. [27] defined the user model as a set of parameters such as personal information, general characteristics, education, occupation, interaction-related info, and user state. General characteristics consist of physical factors such as weight and height, physical disabilities, and abilities like reading, speaking and writing. Personal information includes the user's name, birthday, address, bank account, and credit card information. The state of the user is described by a set of parameters like current activity, current terminal, location, and orientation.

There are several approaches related to the structure and representation of information in user models. Overlay models [31] are used for modeling user's knowledge as a subset of the domain model. The overlay model stores an estimation of the user's knowledge level for each part of the domain. For the representation of user's interests a common model is the weighed vector of keywords [19]. Weights are related to keywords and express numerical description of user's interests. A user model may be represented by a weighted semantic network [12] in which each node expresses a concept. The use of ontologies constitutes a promising approach for the representation of user models because they facilitate the sharing of information and enhance interoperability. Significant proposed ontologies produced for user and context modeling are the General User Model Ontology [14], the Unified User Context Model [20], and the Ontology based User Model [21]. Finally, Golemati et al. [13] created a user profile ontology that includes mainly static information without modeling dynamic characteristics like the current user position.

2.3 Interoperability of User and Context Models

Interoperability of user and context models is a subject that has been studied extensively during the last decade. Numerous approaches exist that attempt to provide effective solutions to this problem [8]. Recent advances in user model interoperability reveal three basic approaches: 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. More specifically, the user modeling community focuses on ontology based approaches as the basis for the shared-format approach in order to achieve user model interoperability. Typical representatives of this category are the General User Model Ontology [14] and the Unified User Context Model [20]. Heckmann et al. 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. Niederee et al. 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.

It is apparent that by adopting a shared format approach by systems, there are no syntactic or semantic heterogeneity issues to be solved. All the systems use the shared model that is easily exchangeable and interpretable. Nevertheless, the 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 systems to adhere to a shared vocabulary. 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. An example of this approach is given in Berkovsky et al. [2] where the authors introduced a generic framework for user model mediation. 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.

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. Concrete approaches that fall in this category are the Generic User model Component [29], [30] and the Framework for User Model Interoperability [7]. Van der Sluijs et al. introduced the Generic User model Component (GUC) that applies Semantic Web technologies to retain user models and to share user profiles between applications. Carmagnola proposed a Framework for User Model Interoperability that uses a shareable user model preserved by every system in order to participate in the interoperability procedure.

3 Identified User Model Attributes and User Context Dimensions

After having examined the various definitions of user model and user context, we propose in this section our definitions for these two important notions of the Digital Library field.

Definition 1: A *user model* for Digital Libraries is a collection of the most important user attributes, either context-independent or context-dependent, that are captured in order for DLs to behave differently to different users. Context-independent are the attributes that do not change if the context is different. Context-dependent attributes are those that are affected by context variations.

Definition 2: *User context* in a Digital Library is a set of dimensions that affect user interaction with the DL. Specifically, context dimensions influence context-dependent user model attributes that the DL captures. This results in different personalization information provided by the DL for different contexts.

A thorough study of the different context definitions presented in Section 2.1 [1], [4], [10], [17], [18], [23], [24] led to the identification of the following **user context dimensions** that are considered important for Digital Libraries.

- **Role**. The Role is a set of allowed actions that a user is eligible to perform. The Digital Library Reference Model [6] defines three basic Roles that a user can play in a DL: DL End-user, DL Manager, and DL Software Developer.
- **Goal**. The user's goal represents the current purpose for a user's work within a DL and it is the most variable context dimension as it can often change several times within a session. The goal is an answer to the question "What does the user actually want to achieve?" [5].
- **Mood**. Mood represents the user's current emotional state, e.g., happy, sad. It can be acquired by explicitly asking the user to set his mood in the respective field of the DL interface.
- **Location**. Location information includes the user's absolute or relative address. Location can be acquired by the IP address if the user uses a PC or by using GPS information that provides geographic coordinates of the user. The geographic coordinates can be used to understand where the user is, e.g., street, at home, in the car.
- **Time**. Time is an important context dimension. Besides the specification of time in UTC format, a different representation can be used to group various time periods, e.g., working hours, weekend.
- **Device**. Device information is important in order for the DL to provide general services. A device can be a PC, a laptop, or a mobile phone. This dimension also includes information such as screen size, operating system, and memory.

The general characteristic of the aforementioned context dimensions is that they influence context-dependent user model attributes. The selection of some dimensions, e.g., Role and Goal, to be part of the context and not the user model was based on the criterion that these features influence user attributes. The identification of context dimensions is considered difficult and context-acquisition mechanisms are of particular importance. Chen [9] introduced three different approaches for context acquisition: direct sensor access, middleware infrastructure, and context server.

Apart from the above context dimensions, our investigation [5], [13], [15], [27], [28] revealed the following specific attributes for the two user model categories.

Context-independent user model attributes:

- **Contact Information**. Contact information includes basic user's information such as name, country, address, and email.
- **Demographics**. Demographics include personal information like gender, age, birthday, education, etc.
- **Physical Characteristics**. These characteristics consist of eye color, height, weight, etc.
- **Ability**. Ability contains information about user's abilities such as writing, reading as well as user's disabilities such as blindness, deafness, and other physical disabilities.
- **Profession**. This attribute includes information about user's profession such as position, type, and company.
- **Expertise**. This attribute contains all kind of expertise like computer expertise [13].

Context-dependent user model attributes:

- **Credentials**. This attribute includes the user name and the password that the user uses to login to the DL. Credentials depend on the Role that the user plays in a DL, e.g., a user uses other credentials to connect to a DL as a DL End-user and other as a DL Manager.
- **Access Rights**. Access rights embody the related information about user's authority in certain areas and resources of the DL. This attribute depends on the Role that the user plays, e.g., a user has other access rights as a DL Manager and other as a DL End-user.
- **Preference**. This attribute is related to the liking of something or the favoring of one thing over another, e.g., "prefer chocolate, not vanilla", "like green color". Preference may be influenced by all context dimensions. For example, when Kate is happy she prefers to listen to pop songs, whereas when she is sad she prefers to listen to gothic songs.
- **Interest**. Interest can be something that concerns or is important for a user, e.g., interest in music, interest in reading. This attribute may be influenced by all context dimensions. For example, John is more interested in sports than reading during the weekend.
- **Activity**. This attribute contains user's current activity, e.g., search for a book, read an article. Also, Activity can be regarded as the history of the user-DL interaction. It is apparent that Activity may be influenced by all context dimensions. For example, if Ian performs a DL maintenance activity, this is related to the DL Manager Role that he plays. Similarly, if Mary is in Rome, this influences her activity of searching for the book "Rough Guide to Rome".

4 Proposed Ontology for User Representation in Digital Libraries

As we have already identified, ontologies constitute a widely accepted approach for the representation of user models and context information. Ontology is a set of concepts with "is-a" relationships between them. Each concept is a class that may have one or more parent classes. Also, a class has properties describing various features of a class, as well as restrictions on the properties. Each property has a type and could have a restricted number of allowed values, which may be of simple types (strings, integers, Boolean, etc.) or instances of other classes. An instance corresponds to an individual object and has a concrete value for each property of the class it belongs to.

In our work, we propose a Shareable User and Context Model Ontology (SUCMO) for the formalization of the user representation in Digital Libraries. A class hierarchy of the ontology, as displayed in Protégé-OWL, is presented in Figure 1.

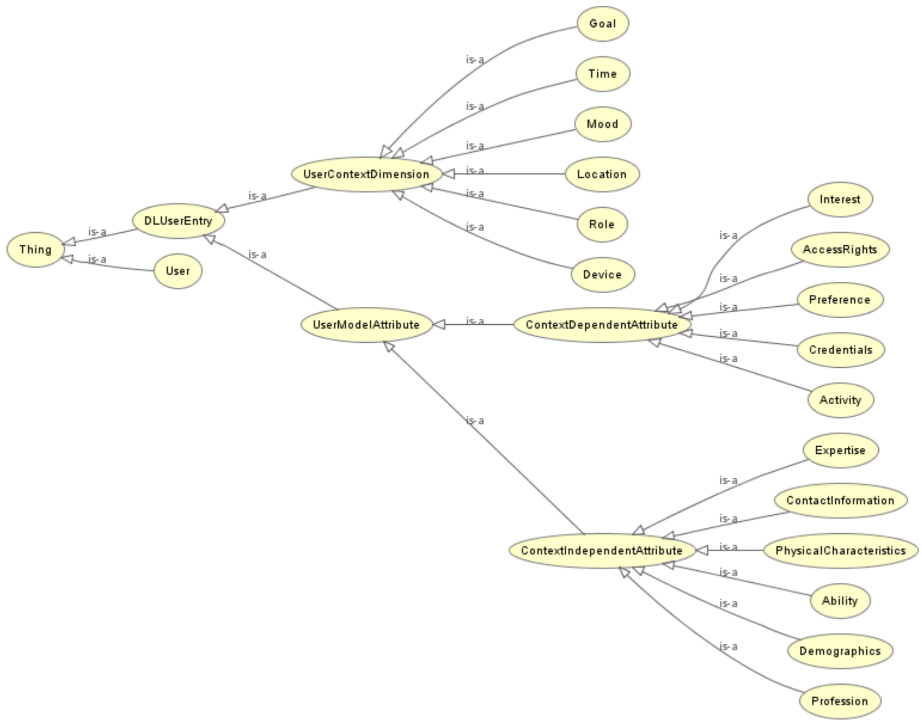

Fig. 1. SUCMO as displayed in Protégé-OWL.

The central classes in the ontology are the "DLUserEntry" class and the "User" class. The "DLUserEntry" is used to provide the hierarchy of the user model attributes and context dimensions that a DL should capture for a user. This class has as subclasses the "UserContextDimesnion" class and the "UserModelAttribute" class that represent user context and user model respectively. The "UserModelAttribute" class is further divided into the "ContextDependentAttribute" class and the "ContextIndependentAttribute" class. Each class contains as subclasses all the corresponding attributes identified in Section 3. Finally, the class "User" is used to describe the user of a DL and contains as properties instances of all the context-independent and context-dependent user model attributes.

It is important to note that each class that represents a basic attribute may contain additional subclasses. For example, the class "Interest" may contain subclasses such as Music, Sport, Book, etc. Here, we focus our investigation on the basic classes and we leave the analysis of the additional subclasses for future work.

The important advantage of using this ontology is that we can connect context-dependent user model attributes with context dimensions, i.e., each attribute may be accompanied by some or all context dimensions. These relations for context-dependent attributes were identified in Section 3. For each context dimension that influences an attribute, a property is created in the specific context-dependent attribute that is an instance of the respective context dimension. For example, we identified that the context-dependent attribute "Preference" may be influenced by all context dimensions. Particularly, the relation between the preference and the user's mood was examined in Section 3. To express this, the class "Preference" should have as property an instance of the class "Mood". In this way, information about preferences can be always accompanied by the mood information. Such a property expressed in OWL Abstract Syntax for the class "Preference" and the class "Mood" is presented below. The same applies for all the other context dimensions and context-dependent user model attributes.

```
ObjectProperty(pp:accompaniedBy_mood
domain(pp:Preference) range(pp:Mood))
```

The significance of accompanying each context-dependent user model attribute with context comes from the need to have better personalization. User's preferences, interests, and other attributes are different according to the context around the user. By enabling this context to be part of each attribute we increase the potentials for the DL to offer better personalization services. In this way, the DL may not only retrace the preferences and interests of the user, but also the context present when these attributes were captured to offer tailored recommendations based on the current context. For example, if John was searching for rock music songs when he was "happy" during the "weekend" and "at home", it is possible the DL system to recommend rock songs when John is "at home", or during the "weekend", or when he is "happy", or for whatever combination of the previous context dimensions.

5 User Interoperability with the Shareable User and Context Model Ontology

As we have already mentioned, the user modeling community focuses on ontology based approaches to achieve user model and context interoperability between systems. Furthermore, Carmagnola [7] van der Sluijs and Houben [29] proposed a challenging approach to achieve user model interoperability that includes as a first step the use of a shareable user model that contains the most used concepts within a domain and as a second step the mapping of user data from one system to another. Typically, this shareable user model could be based on an ontology.

By adopting the aforementioned approach, our proposed Shareable User and Context Model Ontology could be used as a shared ontology among DL systems and mediation methods could be applied to achieve syntactic and semantic interoperability. The user model attributes and context dimensions that are captured in SUCMO are the essential ones to characterize a user in a Digital Library. Mediation methods should be able to achieve syntactic and semantic mapping of user model attributes and user context dimensions from one DL to another. Finally, important is the use of reconciliation and/or concatenation rules for different values of user model attributes and context dimensions, like those proposed in the reference [30].

In order to achieve the above goals, we propose the use of SUCMO as a shared ontology among DL systems. We describe the interoperability process between two systems, the Digital Library Sender System (DLSS) and the Digital Library Receiver System (DLRS). The same steps are applied when more than two systems participate in the interoperability process. The DLSS and DLRS may represent their user and context models using their specific desirable ontologies. The interoperability process, presented in Figure 2, includes the following steps: 1) The DLRS sends a request to DLSS asking to receive information for a particular user (a user profile). Before sending the request, the DLRS performs an ontology mapping between its ontology and SUCMO. When the DLSS receives the request, it checks if it has already performed the ontology mapping between its ontology and SUCMO. If not, the ontology mapping is executed. 2) The DLSS creates the shareable profile of the particular user, by first translating the concepts and relations of its ontology to the concepts and relations of SUCMO. Then, the (probably partial) user profile is generated using the translated concepts and relations. 3) The DLSS sends the user profile to the DLRS. 4) When the DLRS receives the user profile, it starts to analyze it by performing the necessary actions. Reconciliation rules are applied in order to handle the possible different information captured in the two different systems.

In the following sections, we better analyze the different steps of the interoperability process.

5.1 Ontology Mapping

The Semantic Web offers new opportunities for supporting interoperability among Digital Libraries. Ontology mapping is an important aspect of the Semantic Web

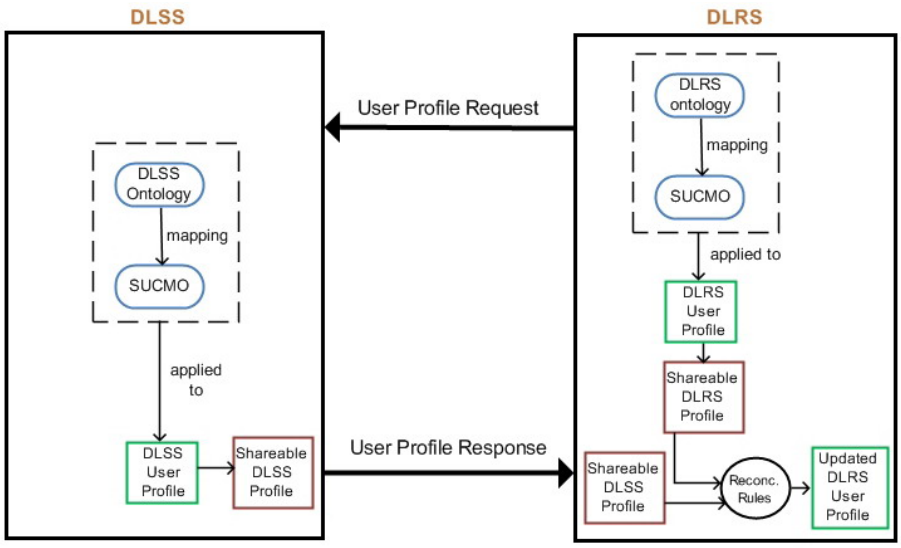

Fig. 2. Interoperability Process.

that is being extensively studied in order to overcome the shortcoming caused by the lack of a standardized ontology and to support information sharing among various systems. As Ehrig and Staab [11] pointed out *"given two ontologies* O_1 *and* O_2*, mapping one ontology onto another means that for each entity (concept C, relation R, or instance I) in ontology* O_1*, we try to find a corresponding entity which has the same intended meaning, on ontology* O_2*"*.

In order to support the mapping between user model ontologies, we adopt the approach presented in the work of Ehrig and Staab [11] titled Quick Ontology Mapping (QOM). The steps of the ontology mapper are briefly summarized below:

Ontology Mapping Algorithm (between ontologies O_1 and O_2)

1. Ontologies are represented in RDF.
2. All entities[1] of O_1 are compared with all entities of O_2.
3. The similarity value between an entity of O_1 and an entity of O_2 is calculated based on Object Equality Function (existing logical assertions), Explicit Equality Function, String Similarity Function (the similarity of two strings based on Levenshtein's [16] edit distance), or Similarity Set Function (to what extent two sets of entities are similar). This step is repeated for each pair of entities of the two ontologies.
4. The aggregated similarity value (the combination of single similarity values) for each pair of entities is calculated.

[1] We use the word *entity* to represent a concept C or a relation R.

5. False similarity values are discarded and the aggregated similarity values with the highest scores are kept.

We applied the above algorithm to map the basic concepts of the UbisWorld and GUMO ontology onto our SUCMO ontology. The result of the mapping process is presented in the following table:

Table 1. Mapping Results

UbisWorld/GUMO	SUCMO
Contact Information	Contact Information
Demographics	Demographics
-	Physical Characteristics
Ability and Proficiency	Ability
Profession	Profession
-	Expertise
-	Credentials
-	Access Rights
-	Preference
Interest Category	Interest
Activity	Activity
Role	Role
-	Goal
Mood	Mood
Location	Location
Time	Time
Device	Device

5.2 Shareable User Profile Generation

After the end of the mapping process, the result will include a subset of the concepts and relations of the original ontology that will have been mapped to the SUCMO. These concepts and relations are, then, translated to the concepts and relations of SUCMO. The result is used to generate the shareable user profiles. In this way, when the DLRS requests the profile of a particular user from the DLSS, which is represented in the original ontology of the DLSS, the respective mapped SUCMO terms of concepts and relations will be used by the DLSS to create its (probably partial) shareable profile to be sent to DLRS. For privacy issues, the DLSS has the ability to restrict the transmission of particular information for a specific user.

5.3 Information Exchange

When the DLSS has created the shareable profile of a user requested by the DLRS, it performs the information exchange process to send the profile to the

DLRS. We assume that the profile is expressed in RDF. We have performed the information exchange process by using in each DL system the open source Java framework Sesame[2] as a server for maintaining user profiles. Using Sesame, systems can exchange user profiles through HTTP requests and responses. The DLRS sends a SELECT-FROM query via HTTP to the DLSS to receive the shareable profile of the specific user. The queries are performed using the Sesame RDF Query Language (SeRQL) [3]. The DLSS sends the query results to the DLRS.

5.4 Reconciliation Rules

When the DLRS receives the requested user profile translated in a language that can understand (the SUCMO), it can easily map the received information of the particular user to the corresponding information maintained by the system.

Reconciliation rules are important to handle the different information captured by different systems. An Information Reconciliation Rule (IRR) defines the action that the DLRS system will perform if an actual value captured in its profile is different from the corresponding value captured in the received profile from the DLSS. General approaches include the concatenation of the two values, the replacement of a value, or the use of a given formula in order a decision to be taken. In our implementation of IRRs, we used a concatenation rule for critical values (e.g., different values for preferences), a time-stamping rule for contradicting values (e.g., the value with the latest time-stamp replaces the other value) that is related to the trust a user has in the particular DL system (e.g., in some cases the time-stamping rule is not applied if the user doesn't trust the respective DL system).

6 Conclusion and Future Work

In this paper we addressed the issue of user context and user model for Digital Libraries by providing definitions for these two important notions. Then, we distinguished context dimensions from user model attributes. These user model attributes were divided into two categories: context-independent attributes and context-dependent attributes. Inspired by the use of ontologies as a tool for information sharing, we created a Shareable User and Context Model Ontology for user representation in DLs. The important characteristic of this ontology is the use of properties that allow context-dependent user model attributes to be accompanied by context dimensions. In this way, along with preferences, interest, and other attributes the context present, when the previous features were captured, is retraced in order for the DL to provide better personalization services. Finally, we proposed the use of SUCMO as a shared ontology among DL systems and we presented our interoperability process that included ontology mapping, generation of shareable user profiles, information exchange, and reconciliation rules.

[2] http://www.openrdf.org/

Currently, our work continues on several directions. We evaluate the possibility of amending and enhancing SUCMO with additional user model attributes and context dimensions. Furthermore, we examine the application of ontology mapping process to other user model ontologies. Finally, we work on defining additional Information Reconciliation Rules that will be based on the different user model attributes and context dimensions.

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