An Ontology-Based Framework for Modeling User Behavior—A Case Study in Knowledge Management

Article *in* IEEE Transactions on Systems Man and Cybernetics - Part A Systems and Humans · August 2011

DOI: 10.1109/TSMCA.2011.2132712 · Source: IEEE Xplore

1 author:

Liana Razmerita
Copenhagen Business School

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Liana Razmerita

Abstract—**This paper focuses on the role of user modeling and semantically enhanced representations for personalization. This paper presents a generic Ontology-based User Modeling framework (OntobUMf), its components, and its associated user modeling processes. This framework models the behavior of the users and classifies its users according to their behavior. The user ontology is the backbone of OntobUMf and has been designed according to the Information Management System Learning Information Package (IMS LIP). The user ontology includes a Behavior concept that extends IMS LIP specification and defines characteristics of the users interacting with the system. Concrete examples of how OntobUMf is used in the context of a Knowledge Management (KM) System are provided. This paper discusses some of the implications of ontology-based user modeling for semantically enhanced KM and, in particular, for personal KM. The results of this research may contribute to the development of other frameworks for modeling user behavior, other semantically enhanced user modeling frameworks, or other semantically enhanced information systems.**

Index Terms—**Knowledge management (KM), knowledge sharing, ontology, personalization, semantically enhanced knowledge management, Semantic Web, user modeling, Web services.**

I. Toward Personal Knowledge Management

AS KNOWLEDGE is at the center of most of human activities, managing knowledge and knowledge management (KM) are an important endeavor for individuals and organizations. Even though there are many nontechnological facets of KM research and practice, modern KM is inseparable from a consideration of technology [1] and emerging technologies such as Social/Semantic Web. KM systems (KMSs) are information systems dedicated to manage organizational knowledge [2]. The first generation of KMS aims to enable simple ways of storing, accessing, sharing, and using knowledge more effectively. Traditionally, corporate KMS consists of databases, intranets, and groupware systems [3]. Formal processes associated with the management of knowledge are time consuming, perceived as cumbersome to use and often have represented a barrier for the use of the systems. Modern KM tools will enable easy free authoring and content creation (through blogs and wikis) and, in addition, better structure knowledge and better support knowledge work (e.g., finding and retrieving information). The focus of new KMSs and practices is placed on sharing and creating knowledge, which, in turn, lead to innovation and improved effectiveness at both individual and corporate levels [4].

The emergence of Social and Semantic Web technologies has brought new possibilities to interact, communicate, share knowledge, collaborate, and manage knowledge. New generations of KMS go beyond the mere administration of data; they will better support the management of tacit knowledge, learning processes, knowledge creation, knowledge sharing, and collaboration between employees, irrespective of their location, using a variety of new applications such as social networks or semantic social networks, wikis or semantic wikis, blogging or semantic blogging, and/or microblogging. New KM tools exploit the new opportunities of sharing knowledge and interacting with customers, suppliers, and partners taking advantage of new social collaborative services and tools available on the Web and in distributed computer networks. Furthermore, these new emerging killer applications combine sharing information, knowledge, and social dimension and undermine principles like information asymmetry and top–down content delivery [5]. Semantic Web technology is key for moving toward collaborative semantic-based KM [6]. In the context of Web access, only authorized individuals must be permitted to execute various operations and functions in an organization, and secure KM must be enforced. Secure KM is critical, as organizations have to protect their intellectual assets [7]. More recently, the concept of personal KM has been developed. While the traditional view of KM is placed on the management of organizational knowledge, which is the collective knowledge, personal KM is focused on the individual on his quest to find, learn, and share knowledge and to socialize [8]. One of the key objectives of personal KM is to help individuals become more effective, supporting his/her rapid development, learning new skills and knowledge [9].

In this paper, it is argued that user modeling processes and personalization mechanisms can contribute to bridge the gap between KM and personal KM. Personalization of a KMS is the process that enables interface customization and adaptations of the functionality, structure, content, and modality in order to increase its relevance for its individual users [10]. Personalization is a pervasive phenomenon in all human activity, encompassing decoration reconfiguration, modification, and customization of software or human-made objects [11]. Within this paper, personalization is extended beyond customization and adaptation mechanisms at the level of the user's interface; the emphasis is placed on personalized user support for knowledge workers. This paper places special emphasis on the link between user

Manuscript received November 15, 2008; revised July 15, 2009 and June 23, 2010; accepted September 20, 2010. Date of current version June 21, 2011. This paper was recommended by Associate Editor E. M. A. Damiani Lytras Naeve.

The author is with Copenhagen Business School, 2000 Frederiksberg, Denmark (e-mail: liana.razmerita@cbs.dk).

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Digital Object Identifier 10.1109/TSMCA.2011.2132712

modeling and the support of knowledge worker's activities, such as create knowledge, share knowledge, and learn and get feedback based on his/her activity in the system. This paper focuses on the role of semantically enhanced user modeling services for personalized user support within KMS. This paper presents a generic framework for modeling users' behavior based on ontologies (OntobUMf). The model of users' behavior includes three subbehaviors: level of knowledge sharing, level of activity, and type of activity. OntobUMf was designed and implemented in the context of the Ontologging project. Ontologging has developed methods and tools for corporate ontology formalization and formal ontology definition methods for KM. Based on the analysis of the evaluation results, this paper shows that adaptation methods and personalization techniques relate to specific needs of the knowledge workers and specific challenges and objectives of KMSs. Knowledge workers are autonomous and cannot be coerced to share or provide knowledge. They must be motivated and/or they should perceive the benefits of using such a system. Knowledge workers want systems that enable to access timely the "right" information, reuse past experience, be able locate experts in the organization, and save time. At an individual level, these specific needs relate to a personal dimension of KM, while at an organizational level, general objectives and challenges of managing knowledge relate to a more collective dimension of KM. Among these general objectives and challenges are how to motivate knowledge workers to share knowledge, how to facilitate/stimulate collaboration between knowledge workers irrespective of their location, how to simplify business processes and work tasks, how to alleviate information overload, and how to foster innovation and creation of new knowledge.

The remaining part of this paper is structured as follows. Section II includes a literature review of the ontology-based user modeling and semantically enhanced KM. Section III describes the Ontology-based User Modeling framework (OntobUMf), its different components, and the associated user modeling processes. Section IV discusses some evaluation results, some of the lessons learned, and its possible implications for future developments of semantically enhanced KMS. Section V includes conclusions and future lines of research.

II. Literature Review

In the last few years, the concept of ontology has started to be used in connection with Semantic Web research. Ontology-based representations are powerful representation structures. The usage and application of ontologies are increasingly seen as the key to enable semantics-driven data access and processing [12] or semantically enhanced search. An ontology can be defined as a set of knowledge terms, including vocabulary, semantic interconnections which can be associated with inferences, "inferencing," and smart queries for any particular domain. Inferences or "inferencing" means that, given some stated information, one can determine other related information that one can consider as it had been stated [13]. Ontology languages can be classified based on the knowledge representation formalism in which they are represented: enriched first-order predicate languages, frame-based approaches, and description logics. Semantic Web research has devoted an important effort in defining a common language for ontology modeling and reasoning with the objective to achieve semantic interoperability. The Web Ontology Language (OWL), which is a language based on description logic, has become the recommended language by the World Wide Consortium in 2004. However, adding additional layers and particularly a rule layer on top of OWL is still a central task for the Semantic Web [14]. Rules and associated reasoning mechanisms are important for instilling intelligence on the Semantic Web and, in particular, connecting and making better use of the data, information, and the collective knowledge harnessed by the various types of applications. Rules and metadata, along with user's preferences, goals, needs, and interests stored as a user ontology, will constitute the core underlying architecture for Human Semantic Web. A human- or usercentric approach will imply a change from the current "push approach" toward a personalized "pull approach" in knowledge and learning management paradigm [15]. User's interests, goals, and needs could be a basis for achieving this pull approach and furthermore be a basis for establishing collaborations and networking with other peers, friends, or colleagues. In the evolution of the Web, three different semantic stages can be distinguished: semantic isolation, semantic coexistence, and semantic collaboration [15]. These stages will eventually lead to semantic interoperability or "semantic collaboration," which are a key for achieving the Human Semantic Web vision [15].

The development of Semantic Web technology has created the context of different semantically enhanced user models either for the purpose of creating distributed user/learner models [16] or/and as an attempt to share them across different types of applications [17], [18]. Previous user or student models were represented by means of logic-based formalisms, such as predicate logic, and later using semantic networks, conceptual graphs, databases, frames, and objects. The logic-based formalisms, such as predicate logic, have the advantage of simple well-defined associated reasoning mechanisms, but they lack structuring properties. Nonlogic-based formalisms are object-oriented representations, rule-based representations, neural networks, semantic networks, conceptual graphs, etc. Nonlogical representation formalisms are more appealing, more intuitive, and easier to understand by nonexperts. In the past few years, ontology-based user modeling has been proposed for different application scenarios. User-modeling-associated rules and ontology-based representations for real-time ubiquitous applications in an interactive museum scenario have been proposed in [19]. In an ubiquitous computing scenario, users can delegate tasks to different agents acting on various devices with computational capability. Context features and situational statements for ubiquitous computing have been proposed as a general user model ontology in [17] and [18]. The use of semantically enhanced user profiles for Web search applications has been proposed in [20] and [21]. Another strand of research emphasizes the use of ontology for adapted learning content and semantic learning portals [22] that constitute dynamic smart learning spaces [22]–[25]. In the context of the Semantic Web, the specification of standards for the management of personal identities has a great potential for providing intelligent learning services [26]. Semantic Web and ontologies may be a catalyst for learning organizations where ontology-based competency management plays a central role [27].

Up to now, few detailed works have been done related to ontology-based or semantically enhanced user modeling in relation with modeling the user behavior for managing knowledge. The user model proposed in FRODO project focuses on the user tasks and role which are associated with specific information needs. The tasks at hand are triggering different information needs. Furthermore, different persons may have varying information needs with respect to the same tasks, depending on their personal skills and knowledge [28]. The user ontology described in the On-To-Knowledge project [29] uses manually constructed ontologies about skills, job functions, and education. This ontology is dedicated for skill management application.

In semantically enhanced information systems, the ontology represents and structures the different knowledge sources in its business domain, aiming to improve the overall performance of the system [25], [30]–[33]. Existing knowledge sources (documents, reports, videos, etc.) are mapped into the domain ontology and are semantically enriched. This semantically enriched information enables better knowledge indexing and searching processes and implicitly a better management of knowledge. Ontologies offer a flexible and expressive layer of abstraction, very useful for capturing the information of repositories and facilitating their retrieval either by the user or by the system to support the user tasks [34]. An ontology-based system can be used not only to improve the precision of search/retrieval mechanism but also to reduce search time [35]. For these reasons, ontology-based approaches will likely be the core technology for the development of a next generation of semantically enhanced KM solutions. However, bringing semantically enhanced information systems to a real-world enterprise application is still a challenge. One reason could be that ontology-based conceptual representations lack certain features which are important for classical database-driven information systems. Features such as scalability, persistence, reliability, and transactions standardized in classical database-driven applications are typically not available in ontology-based systems [36]. Furthermore, an ontology-based semantic markup can be used as a machine-interpretable format for software agents and Semantic Web services to operate. Annotations with well-defined semantics (metadata) can be provided using semantic annotation tools. Authoring annotations for legacy resources is an important effort, and advanced semantic annotation tools need to be made available in order to provide effective semantically enhanced KMSs [37].

III. OntobUMf

OntobUMf has been designed as a three-tiered application server dedicated to manage information about users [38], [39]. The server is generic, designed as a modular architecture that may be extended and used for any application domain. The user modeling server acquires and maintains the user's data through a user profile editor (explicitly) and through different user modeling techniques (implicitly). As shown in Fig. 1, the

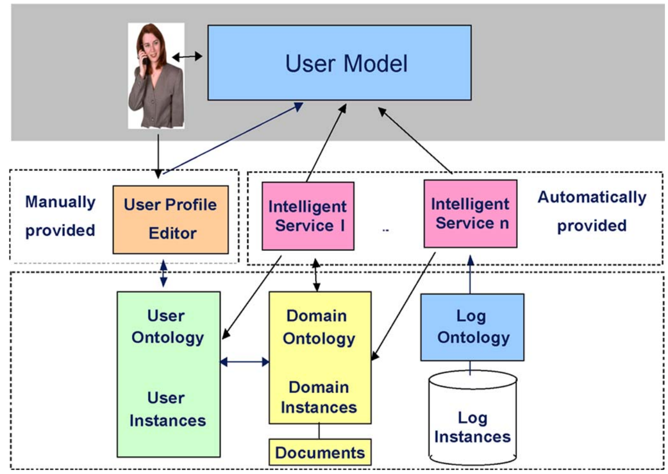

Fig. 1. Ontology-based user modeling architecture.

Fig. 2. User profile editor, in the edit mode.

layers consist of the following: 1) the user front end layer on top; 2) a middleware layer or a service layer; and 3) an ontology and a data layer at the bottom.

The user front end layer consists of tools that enable the user to access and update his/her user model or user profile. The user profile editor is specialized ontology editors dedicated to instantiate and/or visualize the user ontology. The user profile (see Fig. 2) initializes the user model, but it also enables users to visualize and update it. Furthermore, this tool enables users to scrutinize their behavior, their level of activity, the type of activity, and the level of knowledge sharing. The user model is an open user model which is expected to create awareness of the identified behavioral model, enable comparison with other users, provide feedback, and maybe activate a social norm of behaviors. Recent research suggests that, with the appropriate interface, a user ontology may become an easily customizable repository of information that may serve as a memory aide for the user and a tool that may be used for personal information management [34].

The service layer includes several dedicated intelligent services. The user modeling techniques and the personalization mechanisms are represented as intelligent services. The service layer is responsible for handling requests and communicating with the data layer. Services can access the user ontology which is persistent on the server. The user model can be accessed directly by invoking functions of a Web service in order to provide personalized/intelligent services. OntobUMf has a modular architecture which allows adding incrementally different intelligent services. The layering associated with the modular design allows bundling the functionalities provided. The services have two main roles in the system.

1) To update and maintain the user model on the basis of usage data available from the running system through the category extractor. The **category extractor** integrates specific mechanisms for modeling the characteristics of the users interacting with a KMS. Other types of inferences and reasoning mechanisms specific to other application domains can be defined and integrated in the future.
2) To provide a set of **personalized services** based on the characteristics of the users. A personalized service tailors the information provided, taking into account the user's characteristics (e.g., interests, type of activity, expertise, or context). The personalization of a KMS may be defined as the process that enables interface customization and adaptations of the functionality, structure, content, and modality in order to increase its relevance for its individual users [10]. The adaptation techniques can be classified into three categories: adaptation of structure, adaptation of content, and adaptation of modality and presentation [40]. Personalized services include a multiagent system that extracts information from the user profiles. The multiagent-based architecture includes a user agent, a yellow page agent, an interest monitor, a secretary agent, and a number of conflict-detection agents. A further description of the multiagent system can be found in [41]. This multiagent system focuses on coordination and cooperation agents. Security considerations and security policies have also to be considered for sharing knowledge in virtual communities for distributed KM by means of normative multiagent systems [42]. Agents can be knowledge providers who respect global policies. The rules of policies for secure KM do not concern only what knowledge that the users are prohibited or permitted to access but they also concern which regulations that the knowledge providers are allowed or obliged to enforce [42].

The data layer includes user data which are related to domain specific data. The semantics associated with the domain and user model is mapped into the user and domain ontology. Ontologies capture the concepts and the relationships between the concepts describing the different resources available in the system. OntobUMf has access to three different ontologies. User's ontology concepts are related to the domain ontology concepts. The activity of the users in the system is described in the log ontology, and it is captured as log instances. The ontologies are known and mapped manually at design time. Although semantic technologies are designed with extensibility and openness in mind, current programming languages and tools are not able to fully exploit it. It is expected that future semantic applications will be using multiple ontologies, discover them, and integrate them on request [43]

The **user ontology** structures the characteristics of the users in concepts, subconcepts, properties, and their relationships. The user ontology has been developed based on a top–down approach starting from the Information Management System Learning Information Package (IMS LIP) specification, employing the Ushold and Gruninger methodology [44]. It has been specified taking into consideration end-user requirements provided by two Spanish companies involved in the Ontologging[1] project combined with research drawn from research fields such as user modeling, adaptive hypermedia, and user-adaptive interaction and KM. The user ontology is conceptualized according to IMS LIP specification: "The intent of the specification is to define a set of packages that can be used to import data into or extract data from an IMS compliant learner information server" [45].

The IMS LIP is structured in 11 groupings in order to enable learners to customize their experience and formulate it in a general form. These groupings include the following assimilated concepts: identification; goal; qualifications, certifications, and licenses; accessibility; activity; competency; interest; affiliation; security key; and relationship. According to the IMS LIP specifications, the learner information can be packaged from a variety of systems that are not limited to human resource management, student information, and/or learning management systems. A more detailed description of the way in which the ontology has been built can be found in [46].

Behavior is defined as a concept that models the characteristics of a user interacting with a system. The Behavior concept is an extension of the existing IMS LIP concepts. Inferred fields grouped as behavior are calculated based on the data extracted from the log files (the traces of the users). For a KMS, heuristics and fuzzy logic rules allow the measurements of the $Type\_of\_Activity$, $Level\_of\_Activity$, and $Level\_of\_KnowledgeSharing$ of the users in a KMS. Apart from the Behavior concept, which is specific for KMS, the user ontology is based on IMS LIP specifications. Therefore, it is, to a large extent, domain independent, and it can be applied or extended to other application domains if necessary (e.g., Human Resources Management Systems, e-Learning, etc.). Some of the user's characteristics could be filled in by the users using a user profile editor or imported in the user ontology, while others can be inferred based on the user's interaction with the system. Some of the user's dimensions are static, while others are dynamic; some features change fast, while others can change slowly in time.

The **domain ontology** describes the domain knowledge in terms of concepts and relationships between various concepts. The domain ontology can conceptualize different application domains (e.g., e-commerce, e-learning, etc.). The Ontologging domain ontology is centered around the administration of tenders. The domain ontology has been developed at different stages as the first domain ontology that faced a series of prob-

[1] http://www.ontologging.com/

lems at the usage stage. The terminology used in the everyday tasks by the knowledge workers was not the same in the conceptualization of the domain ontology. A set of too generic concepts was confusing for the end-users, so they were misused or used for everything. Consequently, concepts which were too specific have never been used. A set of missing concepts has also been identified for usage. The ontology re-engineering process of Ontologging project has emphasized the fact that achieving a shared conceptualization is not a straightforward process.

The **log ontology** defines the semantics of the user interaction with the system. It describes the user's actions and the associated events triggered in the system. These events, described through the log ontology, are captured as log instances. The specification and implementation of the ontology are generic enough to allow the ontology to be adapted to different application domains.

A. Modeling User Behavior

Modeling user behavior is an ongoing challenge in different application domains, including KM, e-commerce, decision support, e-learning, and marketing. Such advanced systems allow having a better knowledge of the user (in terms of needs, preferences, or goals) in order to offer him/her enhanced services and better support users. Modeling human behavior, by learning from humans, may be also applied to achieve realistic agents' models in various domains [47]. There are many dimensions and elements that need to be considered when building a user model for a specific application domain [48]. Most of the studies of Internet user behavior are based on statistics of user traces and traffic measures [49]. In this case, user behavior characterization takes into account statistics of user session duration, data rates, application popularity, and user mobility in order to predict trends or make recommendations to the users. Researchers often make use of theories from sociology or psychology in an attempt to reveal the hidden rationality of the user browsing behavior [50], to understand individual differences and cognitive styles [51] or Web browsing strategies and goals [52]. From a social perspective, user behavior has been studied in online communities in relation with behavioral patterns of collaboration in order to understand different forms of motivation [53], to evaluate knowledge-sharing dilemma in order to design interventions to successfully manage organizational knowledge [54], or to understand the different categories of users and their motivation for participation in online communities [54].

The proposed model of user behavior and, in particular, the definition of the level of knowledge-sharing concept make use of the diffusion of innovation theoretical model [55]. Diffusion of innovation theory presents innovation as being communicated through certain channels over time and within a particular social system. Individuals have different degrees of willingness to adopt innovations, and thus, it is generally observed that the portion of the population adopting an innovation is approximately normally distributed over time [55]. Breaking this normal distribution into segments leads to the segregation of individuals into five categories of individual in relation to their attitude toward adoption of innovation (from the earliest to the latest adopters): innovators, early adopters, early majority, late majority, and laggards [55]. Members of each category typically possess certain distinguishing characteristics, as briefly described in the following: **Innovators** are venturesome, educated, and use multiple sources of information, **early adopters** are social leaders, popular, and educated, **early majority** think and make decisions carefully and use many informal social contacts, **late majority** are skeptical, traditional, and usually have a lower socioeconomic status, and **laggards** use neighbors and friends as main source of information, and they are characterized by fear of debt.

So, in order to define our model with respect to the level of knowledge sharing, these five categories of users are mapped using Near's terminology into the following categories of behaviors: unaware, aware, interested, trial, and adopter. Similar to the artificial intelligence models of behaviors, the behavior of the users is correlated with goals, beliefs, and commitments reflected in the user's activity or attitudes. The attitude is defined as a predisposition to respond consistently with respect to a certain modeled task

$$B = \{b_1, b_2, \ldots, b_n\}$$

where B is a set of behaviors; in our case, B consists of level of knowledge sharing, level of activity, and type of activity

$$A = \{a_1, a_2, \ldots, a_m\}$$

where A is a set of attitudes; in our case study, the set of attitudes consists of events reflected in the level of activity and the type of activity of the users.

The exhibited user's behavior is modeled through a set of rules

$$r : (b_i {-}{>}\, a_j, \alpha_{ij})$$

where α_{ij} is the reliability degree of the rule.

Such rules depict the approximate degree of a user behavior under the overall assessment of the different user's attitudes (subbehaviors), which correspond to a membership degree in a fuzzy set. Furthermore, these rules can be treated as a set of fuzzy sets on A, where the membership degree in a fuzzy set f_j, corresponding to an attitude aj, is $\alpha_{ij}.F_j$ is a set of rules for modeling user's behavior $b_i {-}{>}\, a_j, \alpha_{ij}$.

The Behavior concept and its subconcepts (see Fig. 3) were introduced to model two processes that are important for the effectiveness of a KMS, namely, knowledge sharing and knowledge creation. Based on their activity in the system, namely, the number of contributions (NC) to the system and the number of the documents, the user modeling system classifies the users into three categories: ***readers, writers, or lurkers***. These categories are properties of the $type\_of\_activity$ concept. *Readers* are categories of users mostly accessing the resources of the system, while *writers* are accessing and contributing, with resources, metadata to the system. A *lurker* is defined as somebody who does not contribute and who accesses very few knowledge assets in the system. Whenever a user contributes to the system, an associated variable $nb\_of\_contributions$ (NC)

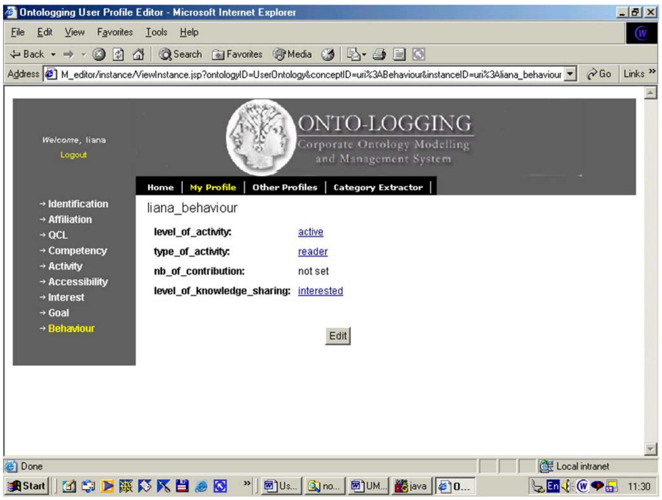

Fig. 3. User profile—the Behavior concept.

is incremented. Similar rules are triggered when the user opens, reads, queries, and provides metadata (tag) or comments on resources available in a KMS.

$\forall x$ ProvideResource->increase(nb_of_contributions(x))
$\forall x ReadResource \text{->} \; increase(nb\_of\_read\_resouce(x))$
$\forall x ProvideMetadata \text{->} \; increase(nb\_of\_read\_resource(x))$
$\forall x Query \text{->} \; increase(nb\_of\_query(x))$

The classification of users according to the $type\_of\_activity$ or to the $level\_of\_activity$ is based on heuristics, taking into account the NC and the number of accessed/read resources (NR).

If $(nb\_of\_read\_papers > NR)$ and
$(nb\_of\_contributions < NC)$
Then $user(x) = reader$'(during timeframe)

where NR, NC, and timeframe are constants that can be parameterized depending on the activity in the system.

The **level of activity** defines four categories of users: ***very active, active, visitor, or inactive***. A **very active** user reads/accesses and contributes with knowledge assets. An **active** user has less activity in the system than a very active user. A **visitor** is somebody who rarely uses the system, while the person classified as **inactive** has no activity in the system. An example of inference rule for classifying the users based on their level of activity is

If $(nb\_of\_read\_papers > NR)$
and $nb\_of\_contributions >= NC + 1)$
Then $user(x) = very\ active$'(during timeframe).

OntobUMf uses the principle of fuzzy classifier systems to assign the users to a certain category according to their level of knowledge sharing. The user's states, in relation to the level of knowledge sharing, are unaware, aware, interested, trial, and adopter. Fuzzy logic is often used to model various types of common-sense reasoning similar to a more humane way of thinking and reasoning. Fuzzy logic extends conventional Boolean logic to handle ambiguity and uncertainty or partial truth. The value between completely true and false is determined by the membership function which takes value in [0, 1]. Fuzzy reasoning was introduced by Zadeh in 1960s to handle the uncertainty of natural language. Fuzzy logic research concentrates on approximate reasoning and reasoning under uncertainty issues. "Fuzzy logic aimed at a formalization of models of reasoning that are approximate rather than exact" [48]. It has been applied to various application domains like knowledge-based systems, knowledge acquisition, control systems, etc.

TABLE I
CALCULUS OF THE LEVEL OF KNOWLEDGE SHARING

$Y=f(x_1, x_2)$	high	medium	low	very low
high	very high	very high	medium	
medium	high	medium	low	
low			very low	very low

We use the principle of fuzzy classifier systems in order to assign the users in different categories according to their level of knowledge sharing.

Fuzzy classifier systems imply a two-step process:

1) to create a fine-grained fuzzy partition;
2) to generate fuzzy rules and calculate membership function or degree of membership.

Through the *level_of_knowledge_sharing*, OntobUmf captures the level of adoption of knowledge-sharing practices based on two fuzzy sets. The system uses the type of activity and the level of activity to codify the membership value of a user to a certain category. In a previous work, users are described as undergoing a change process that brings them from their old practices to the conscious adoption of KM practices (e.g., transition from low or nonexisting levels of knowledge-sharing practices to the widespread adoption of best behaviors in knowledge sharing) through different types of agent-based interventions [56].

The membership of a candidate x in a category is calculated as a function $Y = f(x_1, x_2)$, where

Y the level of knowledge sharing, fuzzified as [very high, high, medium, low, and very low]; these values can be mapped into five categories, i.e., [adopter, trial, interested, aware, and unaware]

x_1 the type of activity, fuzzified as [high, medium, and low], which can be mapped into the stereotypes defined earlier [writer, reader, and lurker].

x_2 the level of activity, fuzzified as [high, medium, low, and very low], which correspond to the categories [very active, active, visitor, and inactive], respectively.

The columns of Table I correspond to the linguistic variables for the level of activity, and the rows correspond to the linguistic variables assigned to the type of activity. The rules are defined similar to a fuzzy controller. No valid rules are applied to the gray cells.

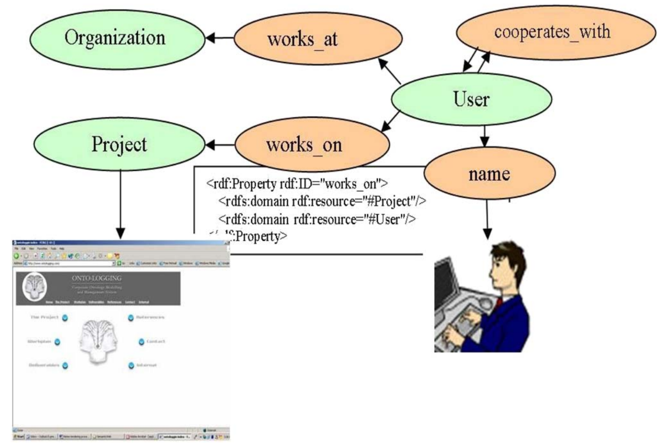

Fig. 4. Application scenario of the user ontology.

Translated from the table, the classifier system uses the following rules.

1) If x_1 is high and x_2 is high, then Y is very high.
2) If x_1 is high and x_2 is medium, then Y is very high.
3) If x_1 is high and x_2 is low, then Y is medium.
4) If x_1 is medium and x_2 is high, then Y is high.
5) If x_1 is medium and x_2 is medium, then Y is medium.
6) If x_1 is medium and x_2 is low, then Y is low.
7) If x_1 is low and x_2 is very low, then Y is very low.

By defuzzifying the aforementioned rules, users are classified according to the level of knowledge sharing into five categories. As introduced before, using Near's terminology and mapping it into Rogers' theory related to the diffusion of innovation [55], the following user states related to the level of adoption of knowledge-sharing behaviors can be identified: unaware, aware, interested, trial, and adopter.

B. Exploiting Metadata and User Modeling

Data and metadata can be used for different scenarios, including personalization, learning and change management, networking and computer-supported collaborative work, and expertise discovery [57]. In the following, we present an example of how metadata and user modeling can be exploited for the management of competencies and management of the tacit knowledge. It has been shown previously that the user ontology describes various properties and concepts relevant for the user model. The concepts of the user ontology are bridged with the concepts of the domain ontology through properties. Fig. 4 shows a part of the user ontology in a graph-based representation. Properties of concepts, such as "works_at," "works_on," and "cooperates_with," associated with ontology specific reasoning mechanisms facilitate further inferences, for instance, the fact that "Smith works_on Ontologging project." Given the fact that the range of the property "works_on" is restricted to the concept Project and Ontologging is described as a project about KM, user modeling, and Semantic Web. Based on these facts, an ontology-based system can automatically infer that Smith might be interested in or has expertise in Semantic Web, KM, and user modeling.

(User, works_on, Project)
(Project, related_to, Topic).

In our examples, the previous resource description framework schema (RDFS) tuples are instantiated as follows:

(Smith, works_on, Ontologging)
(Ontologging, related_to, KM)
(Ontologging, related_to, Ontology)
(Ontologging, related_to, User modeling).

Using associated reasoning mechanisms, an ontology-based KMS can deduce that Smith might be an expert in KM, ontology, and user modeling. Thus, without requiring people to constantly update their profiles (their expertise and interests), an ontology-based KMS could facilitate finding the experts or knowledgeable persons in a domain or domains of interests for the users. Such mechanisms would enable one to make explicit some of the competencies that a user might not be aware of and might help knowledge workers better manage their competencies and skills and thus integrate personal KM features into a KM platform. Furthermore, the inferred user's expertise and interests can be used for pushing relevant knowledge, creating communities of practice, or learning networks where experts and peers can collaborate, interact, communicate, or share knowledge. The overall architecture of a semantically enhanced KM platform emphasizing the points of entry for the user modeling system has been presented in previous publications [38].

IV. Discussion and Evaluation Results

In the recent years, semantically enhanced user models are built following an *ad hoc* approach, a bottom–up methodology, or a top–down methodology. Many user ontologies follow an *ad hoc* approach in their development, taking into account specific goals and requirements of specific applications domains, and do not present details on how the ontology was built [43]. Ontologies may be constructed based on the user's browsing behavior; they may consist of user-interest-inferred concepts, as in the context of Web search [58]. Another bottom–up approach in constructing ontologies is based on automatic metadata extraction from folksonomies, user annotations [59], or tags [60]. For example, user-specific annotation of content may be used to infer user's interests and preferences and used for personalized recommendations of content [59]. Contrary to the bottom–up approach, the OntobUM user ontology follows a top–down approach based on the IMS LIP specification [61]. In the context of Semantic Web, ontologies are meant to be extended, reused, and integrated from different sources. The advantage of using a specification-based approach in developing an ontology is that it complies with a general model, an agreed conceptualization, and therefore, it is interoperable in the sense that it encompasses a set of general concepts that may be exchanged between different applications, extended or enriched to accommodate different types of applications. A similar specification-based approach is proposed in [16]. This learner ontology proposed in Elena project is developed for e-learning applications, using IEEE Public and Private Information [62] learner profile standard. Associated with the learner ontology, a framework for browsing, manipulating, and maintaining interoperable learner profiles has been proposed for e-learning applications in [16]. More recently, a personal ontology for personal information management systems has been proposed in [34]. The authors point out that creating a personal ontology automatically, manually, or semiautomatically is not an easy task. Furthermore, a personal ontology needs to reflect the user individually while it should comply with a general model that enables one to exchange information between users and, at the same time, be usable by computer. An overview of various existing semantics-driven systems taking into account adaptive hypermedia tasks and subtasks and Semantic Web technologies is proposed in [63]. Comparing different user models is not an easy task because user models may be presented at a high level, so user model features might not be presented in detail or, in certain cases, may not be comparable [48]. According to the best of our knowledge, and as presented in the aforementioned survey, no model of user behavior in the context of KM has been presented so far. Previous related work focuses either on skill management [29] or on users' information needs and the associated tasks and roles [28]. Furthermore, as presented in Sections II and III-A, no work proposes a framework for modeling user behavior in the context of KM. As already pointed out in the introduction of this paper, user modeling may contribute to bridge the gap between KM and personal KM in order to better support knowledge work and associated learning processes.

The identification of the objectives, features that the system is expected to support, are elements that contribute to the selection of the evaluation methodology. In the context of a KM, business knowledge processes used in organizations, such as knowledge creation, knowledge acquisition, knowledge structuring, knowledge capitalization, knowledge searching, knowledge sharing, and the support of social/collaborative processes, are important factors to be considered. These particular aspects are to be associated with the short- and/or long-term objectives that a specific organization follows; they can provide insights for the design process itself (summative evaluation) for the functioning system (formative evaluation) or for its effectiveness defined also as substantive value of the solution. The overall evaluation of the Ontologging system focused on the efficiency and effectiveness of an ontology-based KMS. The evaluation of the Ontologging system has mainly taken place at two Spanish companies: a big multinational information technology (IT) consultancy company and a smaller IT company specialized in the design and implementation of enterprise software products (such as accounting, people management, and KM software). The profiles of the employees participating in the experiments were diverse (consultants, software analysts, and system architects), and the employees originate from different domains (security, enterprise resource planning (ERP), etc.). The evaluation of the system has been done by combining the usage data analysis with questionnaires and other empirical evaluation methods, including user studies and semistructured interviews. Taking into account the objectives of this paper, we will limit the scope of the analysis of the evaluation results, and we will further discuss some results of the evaluation pertaining to the specific objectives of this paper. A more complete description of the whole evaluation process, including the methodology, questionnaires, and evaluation results, can be found in the Ontologging system evaluation report [64]. The evaluation was limited for several reasons, among which are also the fact that most of the documents were still in the old KMS, the transfer of data to a new system is not a straightforward process, and the availability of the knowledge workers was limited. As pointed out in [49], statistical tools or models are often used when the quantity of data increases, even if semantic description is the main goal of the study. The focus of the evaluation was the effectiveness of the approach (what is the main value delivered to the users?) rather than the efficiency of the technical infrastructure (are the tools functioning well?) that has been developed. As a consequence, it was decided to use a more qualitative form of evaluation. Data have been gathered through several focus group discussions, semistructured interviews, telephone interviews, and several questionnaires. A number of questionnaires have been elaborated to collect the data: 1) a prequestionnaire (in Spanish) aimed to make a very early assessment of the situation and of the users' needs; the prequestionnaire was designed and distributed to obtain a good understanding of the users participating in the test; and 2) a questionnaire was constructed to evaluate the Ontologging knowledge structuring and content population process, a questionnaire dedicated to evaluate the user-centered tools of the Ontologging system, including the user modeling framework and knowledge distribution agents by the final end-users. The questionnaires included both closed questions (the user has to select a choice) and open questions (the user is asked to use free text to answer). An example of an answer indicating the definition of knowledge tools is given as follows: "*Google may not be KM in the pure sense as I understand it, but it definitely solves most of my problems most of the time*."

The prequestionnaire has been used to collect data related to the end-users' knowledge and practices of KM. This questionnaire was distributed to the group of users before the system was deployed, and 14 questionnaires have been collected. Extracts of the answers provided to the questionnaire related to the KM definitions and suggested associated problems are given as follows:

> *"For me, a KM tool is the one that allows me to access the information I need to perform the tasks associated with my job in a fast and efficient manner."*
>
> *"KM should help people benefit from experience not to have to redo things again."*
>
> *"Part of the problem is to have a system in which people are willing to contribute."*
>
> *KM tools do not improve work. "That is because, currently, it's necessary to spend too much time looking for material."*

The answers to the pretest questionnaires revealed the perceived needs and expectations of the end-users. Users expect KMS to help them easily access information, reuse past experience, save time, and locate experts. The following paragraph quotes are some answers of the prequestionnaire organized according to the most important issues that have been identified as the main pain points for the knowledge workers:

1) to have timely access to information

"To facilitate access to information/knowledge relevant to the current work tasks in order to optimize work processes and improve productivity."

"The most important function is to facilitate access (on time) to [access] useful information in order to make my work easier and best."

"Searching the information that I need."

"Discover and consume the knowledge generated by the company that could help me in my everyday tasks."

"To get briefings of news."

2) to better reuse past experience

"Reuse past experience."

"Reuse company's past experience: documents, experiences, etc."

"Not losing time studying problems which have been solved before."

3) to save time

"Saving time when I am searching for a solution."

"When I must do a tender, I need a lot and diverse information about products, prices, references, news, etc. There is normally little time to do it in and to have information on time if it is necessary."

"A major advantage is saving time when I'm searching for a solution."

"The most important functionality of this system is that it saves me time in searching any kind of information that I need."

4) to find experts and collaborate

"Look for experts in order to ask for tacit knowledge."

"Find the right people to solve concrete problems."

"Also, some KM tool should provide information to know what people know about something or has a previous experience with some technologies and products."

"Direct chat with experts."

In conclusion, as discussed in the previous section, user modeling in KM relates to a number of important issues such as the information overload issue, expressed as the need for enhanced user support, personalization, collaboration support, the need to better manage the tacit knowledge, and the need to find experts. The need for enhanced user support for filtering and retrieving the knowledge available in the system expressed as "to not get lost" among hundreds of documents and to filter "information and noise" underlies the need of better KM tools that support personal KM and personalization. The main issues addressed by the evaluation of the advanced user-centered usages were employees' view on user modeling processes, the perceived need of personalization, and associated incentives for knowledge sharing.

A. End-User's View on User Modeling

Personalized systems require users to submit user data (personal information). The disclosure of user data opens up a series of problems, like privacy and security, but it also opens up new forms of personalization, communication, collaboration, and social interactions. In our case, the user profile editor enables the users to enter and update personal information and thus instantiate the user ontology. The user is in control of his/her "user profile" data. The user profile editor also enables users to visualize another person's profile in order to support collaboration and communication between the employees. User modeling techniques enable one to capture certain characteristics of the users mapped under the Behavior concept. The evaluation of the system has emphasized that the integration of the user models and user modeling in KMSs is a sensitive issue. The questionnaires and semistructured interviews with the end-user underlined the fact that certain users are concerned with privacy and trust issues. This category of users seems to be reluctant to allow the organization to use their data. Therefore, according to the user opinion, the user profiles should be made partially available to the other end-users and fully available to human resources.

B. Motivation for Knowledge Sharing

The behavior of the users can be associated with incentives to share, create knowledge, or be active in the system. Of course, the issue of sharing knowledge, creating knowledge, or contributing to the system is complex and should not be limited to simple incentives (e.g., reputation, ranking, visibility, promotion, and bonus). It might imply changes of the current work practices, and it can be associated with other managerial interventions. We have surveyed different types of incentives that a company might use to stimulate knowledge sharing and knowledge creation. According to the user's opinion, reputation and promotion in organization would be the right incentives to stimulate a knowledge-sharing culture in the organization. However, a bonus associated with the salary also seems to be a good incentive for experts to spend extra time sharing their knowledge. Some expert knowledge workers have expressed their concern in being recognized as experts and having to do extra work.

A totally new vision has emerged, related to the perception of the usage of a semantically enhanced KMS than what was originally envisaged. Ontology-based modeling and Semantic Web technology enable one to go beyond traditional KMS. It is possible to support more complex knowledge-oriented processes by exploiting the metadata and the relationships between the concepts (concept-based navigation). The advantage is the power of the relationships, which enables users to navigate easily from one concept and its instances to another concept and its instances. Metadata and ontology-based representations connect knowledge resources with people. In the user ontology, people are modeled as authors of the documents or contributors, through relationships such as "is_author" and "has_contributor." People are connected with other people through "collaborates_ with" and "works_with" types of relationships. These relationships constitute contextual links among the various chunks of content and enable one to provide a certain support for the management of the tacit knowledge within organizations. The social and personal dimensions will be important features for a next generation of KMS. A personal KM will help knowledge workers manage their competencies, achieve their goals, fulfill work tasks, and support social processes and collaboration with peers and experts or support change management processes. A user ontology, which could be named a semantic e-portfolio [65], could support such goals. The user ontology, along with user modeling processes, will support a more human- or usercentric approach of Semantic Web. Semantic Web can be foreseen to provide more relevant content for the users integrating different sources of information, using mash-ups or other personalized recommendations in order to better harness collective knowledge; to reduce information overload and support attention management; to better support users in searching for information and make recommendations of relevant content using collective intelligence; to better support lifelong learning and personal KM; and/or to better help users to achieve their goal. Personalization will be one of the defining characteristics of a next generation of services where semantics of data will play a key role along with specific goals or characteristics of the users stored in a user ontology.

V. Conclusion and Future Work

Ontologies are increasingly seen as innovative solutions to deal with the exponential growth of information in organizations [66] and achieving the human Semantic Web vision. This paper has presented an integrated framework, called OntobUMf, for modeling users based on ontologies. User modeling processes are targeted to support key knowledge processes and motivate people creating and sharing knowledge, to facilitate collaboration between knowledge workers irrespective of their location and better harness the collective intelligence, to alleviate information overload, to simplify business processes, and to better support work tasks and change management. The Behavior concept has been introduced as an extension of IMS LIP in order to model the behavior of the user—the knowledge providers of the system. A model of the behavior of the user has been proposed, and the classification of the users based on the level of knowledge sharing has been described and implemented using the principles of a fuzzy classifier system. OntobUMf classifies the users according to the level of activity, type of activity, and level of knowledge sharing. The classification process takes into account the level of activity and the type of activity, the characteristics of the users inferred on the basis of the interaction of the user with a KMS. Based on the type of activity, the users are classified into ***readers, writers, and lurkers***. Based on the level of activity, the users are classified as ***very active, active, visitor, and inactive***. Based on the level of knowledge sharing, users can be ***unaware, aware, interested, trial, or adopter***. In a previous work, users are described as undergoing a change process that brings them from their old practices to the conscious adoption of KM practices (e.g., transition from low or nonexisting levels of knowledge-sharing practices to the widespread adoption of best behaviors in knowledge sharing) [56]. This framework is suitable to be adapted and extended in other application domains, such as e-learning, competency management, human resource management, or decision support. User modeling makes a personal KM possible, and it could facilitate users to have better control of their activities and would enable to provide them feedback that could be used to help users achieve their short- or long-term goals. A system which can keep track of their actions, activities, and knowledge processes could model their behavior, and thus, such a system will provide them with a better understanding of their individual actions and/or could even play the role of a change agent in various types of platforms [56], [67], simulations, or games [68]. Nowadays, a knowledge worker needs to be self-sufficient and sometimes needs to unlearn unnecessary knowledge and old habits that get in the way of working smarter and not harder [69].

Semantically enriched resources and ontologies can support the development of a new range of services to enhance user support and lifelong learning. Integration of associated reasoning mechanisms can open up the possibility of making knowledge assets intelligently accessible, associate various types of intelligent personalized services, and create a next generation of services in a corporate setting or on the Web.

Acknowledgment

Part of the work reported in this paper was done in the context of the Ontologging project, which is a European Union-funded project. Ontologging system has been developed by the Ontologging consortium: Center of Advanced Learning Technologies; INSEAD, France; INDRA and Meta4, Spain; Archetypon, Greece; FZI, Germany; and Deltatec, Belgium. The author would like to thank A. Angehrn, T. Nabeth, and the anonymous reviewers of this paper.

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Liana Razmerita received the B.S. and M.S. degrees from “Dunarea de Jos” University, Galati, Romania, and the Ph.D. degree in computer science from Paul Sabatier University, Toulouse, France. Her doctoral research work titled “User Model and User Modeling in Knowledge Management System: An Ontology-based Approach” was done at the Centre of Advanced Learning Technologies, INSEAD, Fontainebleau, France.

She is currently an Assistant Professor affiliated with Copenhagen Business School, Frederiksberg, Denmark. Her previous publications include more than 50 peer-reviewed journal articles, book chapters, and conference papers in domains such as user modeling, Social/Semantic Web, e-learning, knowledge management, and e-government.