Challenges and Solutions of Ubiquitous User Modeling

Tsvi Kuflik, Judy Kay, and Bob Kummerfeld

Abstract Ubiquitous display environments are public places with various situated public displays. These displays are intended to provide relevant information to people in their vicinity, where this may include the regular inhabitants of the space as well as visitors. For this latter group, it is particularly challenging to provide relevant information. This is because personalization relies on the availability of information about the individual (or group). Ubiquitous user modeling research tries to address this challenge. This chapter provides a brief introduction to user modeling and user modeling techniques and then elaborates on ubiquitous user modeling, its challenges, and the state-of-the-art research. It aims to provide a broad introduction to key approaches to user modeling and personalization as a starting point for the reader who wants to appreciate the challenges of personalization for ubiquitous display environments.

1 Introduction

There are many drivers for personalization, but a dominant one is to help people cope with information overload. This problem has been steadily growing with the wide availability of computers and Internet connectivity. In addition, we are now starting to live in "active environments" [60], where the environment senses and responds to us – its inhabitants. This recent development, often called pervasive or ubiquitous computing, offers the promise of new ways to deliver information to people within their current environment, be it their home, office or a public space.

T. Kuflik (✉)
The University of Haifa, Mount Carmel, Haifa 31905, Israel
e-mail: tsvikak@is.haifa.ac.il

J. Kay • B. Kummerfeld
University of Sydney, NSW, Australia
e-mail: judy.kay@sydney.edu.au; bob.kummerfeld@sydney.edu.au

A. Krüger and T. Kuflik (eds.), *Ubiquitous Display Environments*,
Cognitive Technologies, DOI 10.1007/978-3-642-27663-7_2,

Pervasive computing further aims to personalize the information made available to match the individual's current context and task, as well as their individual preferences and taking account of their knowledge, goals and needs. Emerging large displays that are embedded in the environment could be used to deliver timely information to the people in that environment.

Providing personalized information on ubiquitous displays is challenging. This is because personalized applications within a pervasive computing environment must acquire relevant information about the people in the space, so that they can use that information to drive the personalization. When such information is stored explicitly, rather than embedded within the logic of a program, it is called a *user model*. In general a user model may represent various forms of information about the user, such as their current needs as well as their long term preferences, knowledge and goals.

In the case where new users come to an active environment, the applications within that environment will have no prior knowledge of the users. Acquiring user modeling information is quite difficult. Certainly, it would be unacceptable to subject the users to a questionnaire to bootstrap their user model. Instead, a new framework for user modeling is required – "a ubiquitous user modeling framework" which can both capture relevant information about the user in the active environment and make relevant parts of a user model available when and where it is needed. This has been described by Heckmann [34] as follows: "ubiquitous user modeling describes ongoing modeling and exploration of user behavior with a variety of systems that share their user models".

Recent research in user modeling recognized this need and work has started in exploring approaches and techniques for supporting users in active environments. There are three main challenges posed by such active environments:

1. Little initial information about the users that request/need a service;
2. The heterogeneity of existing user modeling information;
3. The need to keep track and adapt a user model continuously for every user in the environment.

Moreover, taking a broader view, it is clear that there are critical challenges associated with effective management of privacy. This is tightly coupled with personalization, since the user model holds personal information which is subject to legal requirements. Privacy is also inextricably linked to security as well.

2 A Short Historical Perspective

User modeling research can be dated to the mid-1970s [49], when technological progress made personalization feasible and research began to explore how to provide personalized services to their users beyond the "one size fits all" paradigm. Importantly, one of the key foundations for that work was based on the recognition of the value of representing information about the user in an *explicit* user model [51], as well as a separate user modeling system to manage the model.

Such a user model could hold arbitrary personal information, such as the user's age, education, income, life style, interests, plans, preferences, past interactions with the system, and any additional relevant information needed by the system to provide a personalized service.

A key task is the initialization of a user model in such systems. Accurate initialization of a user model is important to every system that provides personalized services. In some cases, it is important to reuse the user model. For example, if the user rarely interacts with an application, it needs a means of acquiring the user modeling information efficiently, without bothering the user. In such systems, stored user modeling data from previous interactions is usually not available at the outset. We now focus on ways that user modeling research has developed to address this problem.

2.1 Basic User Modeling Representation and Reasoning Techniques

In more than 30 years of research in user modeling, a variety of user modeling techniques have emerged. Some of these provide ways to represent the user model. Generally speaking, representation and reasoning in user modeling are tightly coupled; hence in every section we will briefly discuss the relevant representation issues. We focus mainly on a selection of techniques that support efficient *reasoning* about the user, especially in cases we start with limited information about them and need to infer more to support the personalization. We have chosen these to illustrate the character of the approaches available, rather than provide an exhaustive review. These approaches include "content-based", "case-based", "collaborative" (or "social"), "demographic", "knowledge-based" reasoning, and various hybridizations of them, as described below, following [31]. These differ in their complexity, the amount of information they keep and their pros and cons as presented below. In addition the use of activation/inhabitation networks and overlay models, that are common in eLearning and cultural heritage will be discussed.

2.2 Feature-Based and Content-Based User Modeling

In a feature based approach, a user model is a set of feature-value pairs, representing various aspects of the user, such as interest in specific sport, music type, level of knowledge in a specific area, and more [9]. This can be at different levels of detail, as needed by the application that matches values of features representing items/information suggested to the user with the features in the user model, in order to determine their similarity or relevance. One commonly used approach for measuring the similarity of items and users assumes the users and items are represented as vectors in an n-dimensional space and the cosine between these two vectors represents the similarity or relevance. This is used to rank the items to be suggested/ recommended to users. The content-based approach of user modeling as described by Hanani et al. [31], is a specific variant of the feature based approach. It takes into account the user's areas of interest, as represented by the textual content of documents the user has previously indicated are relevant or interesting. From this, it creates a richer user model as a basis for personalizing services – e.g. the user model is a set of terms, possibly weighted, representing the area of interest. This approach was initially described, as the "cognitive approach" by Malone et al. [59]. In general, content-based systems analyze the textual content of documents that users rated, to infer the users' informational needs. These systems deduce their recommendations by matching the analysis of user needs with the analysis of available rated items content.

2.3 Case-Based User Modeling

Agnar and Plaza [3] described the general case-based approach as utilizing the specific knowledge of previously experienced, concrete problem situations (cases) where these has been "captured" in a way that enables the system to recognize similar cases later. Humans use this approach as a powerful and frequently applied reasoning mechanism.

The case-based approach covers a wide variety of techniques for organizing, retrieving, utilizing, and indexing knowledge retained from past cases. Cases may be kept as concrete experiences, or as a set of similar cases that form a generalized case. A solution, based on a previous case, may be directly applied to the current case, or modified according to the differences between past and present cases. Matching and adaptation of cases may utilize a deep model of general domain knowledge, shallow and compiled domain knowledge, or no domain knowledge at all. A technique may be purely automatic or depend on interactions with the user.

For a user model, a case is associated with personal characteristics of the user involved. An example may be a tour plan that contains, in addition to the tour plan itself, some personal characteristics of the users who planned the tour. The system can then match new users to previously stored cases to recommend the same plan to other users with similar characteristics, as in the case of Trip@dvice[1] [68].

2.4 Collaborative User Modeling (Based on Matching Similar Users)

The underlying assumption of the collaborative approach is that users with mutual taste who agreed in the past tend to continue to agree in the future [27]. This is

[1] http://www.ectrlsolutions.com/web/guest/tripadviceportal.

a relatively simple user modeling approach that is widely used in deployed recommender systems (for example, Amazon – people who bought this item also bought…). According to this approach, the user model is a list of ratings for items – a vector of ratings, where the dimensions are the individual items (e.g. books, movies, etc.). Following this approach, a system compares a user's model to other users' models by matching items they liked or disliked in order to identify similar users. Once similar users are identified, the system attempts to predict how much the current user will like an item that has yet to be rated. The prediction is accomplished by computing a weighted average over all the item's ratings given by similar users. This approach somewhat resembles the case-based approach. However, it differs from the case-based approach since instead of finding the most similar cases it gives an average score for each item of interest using every available case, without considering its similarity. (The focus is on the similarity of the behavior of the users; hence it is sometime called social filtering [31].) This means that users with correlated preferences are sought. The collaborative approach is useful in domains that contain a variation of interests, such as movies and books. Systems using this approach categorize users with similar preferences as similar users, and use past interactions of similar users to provide recommendations. The collaborative approach suffers from the *cold start problem*: users have to rate several items before they can benefit from the system and items need to be rated before they can be recommended.

It is worth noting that in addition to the *user to user* matching discussed above there is also an *item to item* approach, where the user's ratings for similar items are averaged for prediction of the rating of the target item (instead of averaging ratings of similar users, see Ref. [71]).

2.5 Demographic User Modeling

The demographic approach relies on a marketing approach which postulates that users with similar demographic backgrounds may have similar preferences. This approach uses an analysis of demographic data about users, who rated a certain item, to learn and categorize the "type" of a person who likes the item. This information is stored and then used to provide for future recommendations. Although demographic data is used for marketing, its use in user modeling is relatively limited, since it is *stereotypical* by nature and requires a reference demographic data base that is usually not available. However, in some cases it has been used in research to enhance recommendations in hybrid user model based systems (see below).

2.6 Knowledge-Based User Modeling

Knowledge-based systems infer their recommendations from a knowledge base about products and typical users [13]. Systems applying the knowledge-based approach utilize a domain-specific knowledge base and analytical skills of human experts to advise users who are novices in the field (in performing tasks/searching for information etc.). These systems require domain knowledge that is a result of a knowledge engineering process, which is known to require significant effort from an expert and is time consuming. A domain expert is required to choose a method of representing the knowledge, a method of utilizing it, and a method of structuring it [12]. These methods should allow the system to mimic the experts' solution to a problem. In general, knowledge based systems were quite a focus of considerable research as expert systems in the past but the problems of eliciting, representing and updating such systems means that they have less importance than the other approaches described where automated analysis of data provides models that can be readily updated.

2.7 Hybrid User Modeling

The hybrid approach strives to exploit the benefits of complementing approaches, and simultaneously aims to avoid their downfalls, as surveyed by Burke [14] in the case of recommender approaches. Systems using the collaborative approach need to ramp up with sufficient amounts of data, otherwise they are susceptible to erroneous performance. Until a sufficient number of ratings are collected, the system might not be useful for users for whom there is insufficient data from collaborating peers. A knowledge base generated by an expert may be used to avoid the collaborative approaches "ramp up" problem. A drawback of knowledge-based systems, which the collaborative approach facilitates solving, is the indifference of knowledge-based systems to individual preferences. This could result in a knowledge-based system suggesting a common solution, even when the user exhibits an uncommon behavior. The combination of these approaches facilitates better personalization than would be provided by one of these approaches alone. The drawback of this type of hybrid system is that knowledge engineering is still required as is the case of the pure knowledge-based approach.

2.8 Activation/Inhibition Networks

This approach, when applied to personalization, is tightly coupled with a rich domain knowledge base. A user model is overlaid on a domain ontology, that may be structured, for example as a taxonomy, semantic net or other knowledge base. When there is a description of a domain, represented by a tree or a graph of linked concepts ("domain ontology"), an individual's user model can be represented as a partial graph/tree with the concepts that the user is modeled as knowing or being interested in. The representation may model each node of this model in various ways, for example, a simple Boolean or a numerical value. The user model is adapted by a reasoning mechanism that reasons and propagates new evidence about the user preferences/knowledge level (based on positive/negative feedback) between concepts (preferences, knowledge) along the links from one concept to all the concepts linked to it, applying heuristic decay mechanisms (so propagation stops after a few steps). Overlay user models have been particularly common where systems need a detailed mapping of users' knowledge or interests, in areas like eLearning or cultural heritage.

2.9 Stereotypes and User Modeling

One important notion in user modeling, identified and named by Elaine Rich [69] is the stereotype. This captures the notion that a small amount of information about a user can be used to infer a large amount of other information. For example, if we are told that a person is a judge, we can infer they are highly educated, well to do, honest, and the like. This basic idea was used to create a double stereotype for knowledge of the Unix operating system [91] where observing that a person used sophisticated commands was used to infer they were an expert and knowing a person was an expert was used to infer a default stereotype representing a rich knowledge model, indicating many things that user would know. Similarly, if a person indicated they were novices, this single piece of knowledge was used to infer a detailed default model of their knowledge. This was used to support a natural language advisor and it is representative of an important part of the early user modeling research which was motivated by the demands of natural language dialog. It is also representative of work on intelligent tutoring systems, an important body of work that has spanned the whole of user modeling's history [73]. The notion of stereotype was more tightly defined [44] as a set of default assumptions that are made when a small set of triggers becomes true, with the definition of retraction conditions which can be used to determine that a stereotype should no longer be used. The key idea was that a stereotype should be used to address the cold start problem, by using a small amount of information about the user to infer a rich, statistically valid, initial model that would be used only until more reliable information about the user became available. It was noted that such a stereotype could be used to reason across domains, for example, taking a model of the user's preferences for books and using this to infer a model for the their preferences for movies.

3 Ubiquitous User Modeling and Its Challenges

3.1 Introduction to Ubiquitous User Modeling

While user modeling as a research area began about 35 years ago, the ideas of ubiquitous computing (or pervasive computing or ambient intelligence) have been around from the late 1980s [88]. During the 1990s, topical workshops and conferences on ubiquitous/pervasive computing appeared, followed by new journals and magazines such as IEEE Pervasive Computing that started at 2001.

Ubiquitous user modeling has closely followed the evolution of ubiquitous computing. There was recognition of the link between the goals of ubiquitous computing and the need to support users in such environments by taking into account personal aspects as well as contextual ones [41].

One of the important common ideas in ubiquitous computing and user modeling is that a useful model of a person may well need to draw on evidence from a range of sources. This was central to the um toolkit [43, 45], which distinguished evidence in terms of the nature of its source, for example treating stereotype-based evidence as less reliable than observations of the user's actions, which in turn might be treated as less reliable than information the user explicitly gave to the system. Similarly, Vassileva [84] used stereotypic user models that integrate task and expertise characteristics to bootstrap a user model that was later updated based on user behavior. van Elst et al. [83] suggested augmenting business processes that usually rely on role and task information in order to support their users, with personal information. Hence to integrate user modeling data from two sources – stereotypical contextual information, related to the task and role, with information about the specific worker, for better service. These ideas were used for pervasive computing to model location [18], making use of multiple sources of varyingly reliable sources if evidence, including Bluetooth and system sensors, both prone to various forms of unreliability but together being useful to infer the user's location.

In order to provide a system that can accept evidence about aspects of the user, one needs a framework. The first steps towards this were user modeling shells [49], which provide a representation for the user model and various user modeling tools that can be reused by multiple applications. It should be understood that at the time of that work, applications tended to be stand alone and specific, and user modeling capabilities were integrated into the application. The first step into ubiquitous user modeling was made by decoupling the linkage of the application and the user modeling component and introducing the general user modeling shell systems [49].

During the late 1990s, commercial personalized systems started to appear, with some of these having a client-server architecture. This might be seen as an initial step towards sharing and re-using user data for personalization by different applications [7, 49]. In his survey, Kobsa [49] notes the need for mechanisms to import and export existing user data as a requirement from user modeling server, but without suggesting any mechanism or framework for that process. He also stated correctly that processing done by personalized systems at that time cannot be used outside the context of the specific domain and application due to the lack of abstract representation of learned users' characteristics.

Kobsa [49] detailed requirements that will facilitate wide dissemination of generic user models. (Although he distinguished academic and commercial work, the requirements are complimentary and we integrate them. Technical performance requirements were not included).

- Generality: domain independence, compatibility with as many applications and domains as possible, and for as many user modeling tasks as possible.
- Expressiveness: ability to express as many types of facts and rules about the user as possible.
- Inferential capabilities: capability of performing various types of reasoning and resolving the conflicts when contradictory facts or rules are detected.
- Import of external data: ability to integrate the user modeling data collected by the system with the data collected by other systems.
- Privacy: support of privacy policies and conventions, national and international privacy legislations, and privacy-supporting tools and service providers.
- Quick adaptation: ability to quickly adapt services to new users, personalization functionalities, applications, and domains.
- Extensibility: Provide Application Programmer Interfaces (APIs) and interfaces that allow for the (possibly bi-directional) exchange of user information between user-modeling tools (allowing the integration of variety of user modeling techniques).

Kobsa [49] concluded his survey of generic user modeling systems with fairly accurate predictions of the development of networked computers and especially mobile computing. He suggested two options for ubiquitous user modeling with a user model residing on the server side or even on the mobile device. Furthermore he introduced the notion of personalization of smart appliances, and the potential of multiple-purpose usage of users characteristics and discussed in light of this the pros and cons of client side versus server side user models [93].

Kobsa [49] concludes: "...one can expect to find a wide variety of generic user modeling systems, each of which is going to support only a few of the very different future manifestations of personalization and other applications of information about the user..." The obvious conclusion from the above is that given the expected variety of limited user modeling servers on the one hand, and the usefulness of re-using available precious user modeling data on the other hand, there will be a need for some kind of generic mechanism for user modeling data sharing, conversion and exchange. This is because we cannot expect that all systems and servers will use the same user modeling ontology/language. We refer to such mechanisms as user modeling mediators. Such mechanisms are the essential foundations for ubiquitous user modeling since the very basic need for ubiquitous user modeling is to accumulate and exchange user modeling data with variety of applications, as needed for ad-hoc personalized service delivery.

3.2 Challenges of Ubiquitous Computing

This section provides a very brief overview of ubiquitous computing challenges, in order to introduce the challenges of ubiquitous user modeling. In Weiser's vision for ubiquitous computing, computing artifacts will disappear "They weave themselves into the fabric of everyday life until they are indistinguishable from it." Weiser [89] presented various infrastructure challenges for mobile computing, such as power problems, wireless communication, means of interaction and privacy. All of these have had considerable work since that time. Infrastructure issues are being tackled in various ways (for example, [23, 30, 94]), solutions also have been suggested for ubiquitous collaboration [40], privacy in ubiquitous computing is an important and ongoing area [15, 56, 57], design and evaluation of ubiquitous services [39], integration of context awareness into pervasive computing applications [63], development framework for small screen mobile devices [66], framework for interaction and visualization across small and large screen devices in ubiquitous computing [75] and even pervasive games [81] and more.

In parallel with the various solutions being proposed, new models, visions and challenges continue to appear [1, 35, 55, 70, 72, 87, 89]. There have been papers in which the "state of the art in ubiquitous computing" is reviewed and future research directions are identified [2, 64].

By its nature, ubiquitous computing aims to support individuals in computerized environments. As such, knowledge about the users, their needs, background, preferences, knowledge, etc., is necessary for personalized services. Hence for providing services to users in ubiquitous computing, novel technological solutions, including context awareness, are not enough and classical user modeling aspects need to be addressed as well [41].

3.3 Challenges of Ubiquitous User Modeling

Ubiquitous user modeling must overcome three major barriers – user modeling issues related to *user modeling techniques differences, domain differences* and *contextual differences*, as well as the need to efficiently and effectively bootstrap a user model for ad-hoc services and continuous updating of the user model. Let us use a brief example to illustrate the above requirements. A user is searching for a music CD as a birthday present for a friend. The user enters a store that they have not visited before. The store has a collaborative recommender system. Consider the first time the user accesses this system. Suppose the user has previously used a content-based music recommender system and his/her content based profile is available for the collaborative music recommender system. To make this useful for the store system, there is a need to convert the existing content-based user model to a collaborative one – or "cross technique user modeling mediation[2]". Now assume that instead of the content-based music user model, there is a collaborative movies user model (e.g. taken from movielens[3]). Now the challenge is how to

[2] Mediation is explained in detail in the next section.

[3] http://movielens.umn.edu/.

convert the movies user model to a Music user model – “cross domain user model mediation”. The third aspect can be illustrated as follows, assume that there is a user model for that user at that online store – the user purchased several CDs for personal use in the past. However, this time they are searching for a present for a friend – a different context that probably requires a different user model (the friend’s user model?), hence this is “cross context user model mediation”.

It is worth noting that even systems that utilize the same approach may use different techniques in applying them. For example, two content-based systems may differ in their weighing scheme. One system may weigh every term extracted from the available contents and the other may categorize the terms, weighing the categories instead. Or, two book recommender systems may rate the books on two different scale – one on a scale of 1–10 and the other from −2 to +2. Consequently, different systems may well store user modeling data according to their own representation.

In an active environment, the envisioned scenarios may be a mix of representation, domain and context (e.g. to recommend a restaurant for dinner with a friend, using the collaborative approach, a system may need to integrate content-based information about books with restaurant preferences for lunch with colleagues). Hence, the available information may be from different domains, in different contexts, and represented in different techniques due to natural heterogeneity of the systems and services available and the dynamic contexts of the users.

Assuming that there are user models for this user, in various domains and applications, the challenge of ubiquitous user modeling is how to efficiently and effectively make use of these to construct an ad-hoc user model to drive a personalized service for a first time user in an active environment, from various heterogeneous user modeling sources?

Research in ubiquitous user modeling is trying to address this question in various ways, as described below.

4 Bridging the Gap: State of the Art of Ubiquitous User Modeling

The user modeling community recognizes the need for data sharing, based on standards and/or mediation. This is needed to enable and improve personalized services by making user modeling data available to a variety of applications beyond a single application which defines its own user model. Even though semantic web ideas offer the promise of ease of data sharing and possible standardization, techniques are needed to bridge the gap between the ideal semantically unified user modeling domain and today’s practice – heterogeneity of user models, as recognized in Kobsa’s requirements for user model data import and extensibility [49]. Beyond that, for supporting users in active environments when personalized services are delivered as needed, accurate user modeling data is essential. Among current research projects we can find attempts to standardize user modeling terminology in order to allow easy collaboration by the use of common ontologies and languages, general servers that allow partial views, as needed, to applications, importing and exporting user modeling data, hybrid user models, adding contextual aspects to better support users by taking into account their specific context and user modeling mediation. The following sections will survey the state of research.

4.1 Common Semantics for User Modeling

Common language is a key issue in integrating information from different sources in every domain, including, of course, user modeling. Ontologies, common languages and communication protocols are among the commonly accepted approaches to achieve this, while the advent of the semantic web provided a common platform that encourages and supports them. The state-of-the art approach to the problem of standardization of domain specific knowledge representation is the use of ontologies. Ontology-based representation of user modeling was discussed in Ref. [46], which motivated ontology-based reusable and understandable modeling of students. Reusability makes use of the separation of the user model from the personalization application or application domain. The structure of the user models was based on a set of predefined ontologies that facilitated access to a customized explanation of the meaning of the user modeling components in each domain. However, in spite of the great potential in the use of ontologies, they have not become widely used in user modeling tasks, possibly due to the initial effort required in the construction of domain ontology.

Dolog and Nejdl [21, 22] proposed an approach where a learner model can be distributed and can reflect features taken from several standards for a learner modeling. These features can be combined according to the requirements of specific personalization techniques, which can be provided as personalization services in a peer-to-peer learning network. They analyzed various usage scenarios and defined conceptual schema for learner feature categories. Denaux et al. [20] pointed out in a position paper the potential of combining ontologies for student modeling, especially when they follow standards.

The evolution of the semantic web provided the needed infrastructure for information standardization and sharing, including user modeling data. Henze and Kriesell [37], Henze and Krause [38] proposed a service-based architecture for bringing methods and techniques from the area of adaptive hypermedia to the Semantic Web (thus extending the adaptive hypermedia framework to the adaptive web [10]). In their framework, personalization functions from adaptive hypermedia were made available as web services, which a user can subscribe/un-subscribe to as they prefer. They have implemented their ideas in a Personal Reader, a framework for defining rule-based personalization algorithms for Semantic Web applications.

Their framework includes a Dublin-core[4] or LOM[5] based domain ontology and attribute-value pair user modeling ontology, an observation ontology, and an adaptation ontology. In their demonstration they provide a learner device while relying on LOM, user profile information is relying on the IEEE PAPI[6] specification for describing learners as building blocks and on RDF[7] for information sharing, thus standardizing the access to the user modeling data. This makes it potentially available to other applications following the same standards. However, the standardization of user model relies on IEEE PAPI hence it is limited to the tutoring systems domain and cannot be generalized beyond that, unless another standard (such as GUMO) is adopted.

The notion of ontology-based user models was further developed by Razmerita et al. [67], who presented a generic ontology-based user modeling architecture called OntobUM. OntobUM integrated three ontologies: a user ontology characterizing the users, a domain ontology defining the relationships between the personalization applications, and a log ontology defining the semantics of user-application interaction. A similar approach for ontology-based representation of the user models was presented by Heckmann [34]. He introduced GUMO, a comprehensive set of General User Model Ontologies, which allowed uniform interpretation of distributed user models in intelligent environments. GUMO represented user modeling data using the RDF[8] based OWL,[9] and was used for multiple personalization applications which operate at the same time. Such commonly accepted ontologies simplify the exchange of user modeling data between personalized applications and overcoming the inherent problems of syntactical and structural differences between their user modeling representations. The diversity in the area of user modeling also triggered the User Modeling Meta Data Ontology initiative UMMO [96] that was meant to structure the state-of-the-art in the field and serve as a central reference point and as a tool to index systems, papers and learning media. Such an ontology is beneficial for both the user modeling research community and the students, as it creates a shared conceptualization of the known approaches to building user models and their implementations (it seems that it was abandoned, since its links no longer function). A similar approach was also taken by several other researchers: Weiβenberg et al. [90] suggested the use of a complex hierarchy of ontologies for personal recommendation of events to mobile users; Mehta et al. [61] suggested using a common ontology for standardization of user modeling across systems; Brusilovsky et al. [11] suggested use of a common

[4] Dublin Core, 2004. http://dublincore.org/.

[5] LOM: Draft Standard for Learning Object Metadata, 2002. http://ltsc.ieee.org/wg12/index.html.

[6] IEEE P1484.2 Learner Model Working Group, PAPI Learner, draft 7 specification, 2003. http://ltsc.ieee.org/wg2/papi learner 07 main.pdf.

[7] Resource Description Framework (RDF) Schema Speci_cation 1.0, 2002. http: //www.w3.org/TR/rdf-schema.

[8] Resource Description Framework, available online at http://www.w3c.org/RDF/.

[9] OWL http://www.w3.org/2004/OWL/.

ontology for representing users' domain knowledge to be used by different personalized eLearning systems; Hatala and Wakkary [32] used an ontology for tagging domain objects and to allow reasoning about the user that is more abstract than reasoning based on content; Zhang et al. [97] suggested using web services as a mechanism for exchanging user modeling data among systems sharing a common user modeling ontology; Carmagnola et al. [17] used a common ontology, so allowing users to tag objects and share information for socially-based personalization. All the above (and many more) involve an initial intensive effort in creating the relevant ontologies. An alternative approach to manual construction of ontology is to learn a light-weight ontology, by mining available materials in the pervasive computing context [65].

The need for standardization of user modeling was recognized beyond the user modeling research community. As early as 1999, the need for standardization of user data for possible exchange of customers' data, lead to standardization work by an industrial consortium. The goal of the work was to support vendor-neutral interchange of customers' data for e-businesses and at the same time to provide a framework enabling privacy safeguards. The result was the definition of Customer Profile Exchange (CPExchange) specification for the privacy enabled global exchange of customer profile information. The proposed standard uses the Extensible Markup Language (XML) to format messages transmitted under standard Internet protocols and includes both a Customer Information model and a Privacy Information model. The information models contained in this specification facilitate customer profile transport and include the metadata that associates data protection (privacy) with customer profiles. The specification builds on the W3C XML Schema and the W3C P3P specifications [8].

As demonstrated above, there is an abundance of work exploring ways to apply social and semantic web techniques for user modeling interoperability (for further reading see a recent survey by Torre [80]). However, all face the need for agreement upon user modeling and domain ontologies; at this point, such agreement has not been achieved.

4.2 User Modeling Servers

The progress towards user model servers can be seen to have started with work on "user modeling shells", with their generic components for user modeling [48]. However, once it was realized that the personal information is important as well, user models that store personal data and provide it to applications for personalization appeared.

In 1995, Kay developed the um toolkit [45], a mechanism for reusing generic user modeling data for different applications. The core of the system is a repository of information about the user and this was stored in the user's own filespace. Each application can interpret the user modeling data in different ways using a "resolver" function that interprets the evidence about each component in the model. There were several built-in resolvers but the application could also apply its own.

This tool evolved into Personis [47] and its descendants, where the key difference is that a server stored a collection of user models for many users. Notably for pervasive computing, PersonisAD allowed for models that could be distributed [4]. Authorized applications could request access to the model. If that access was allowed, multiple applications could use and reuse the allowed parts of the model. The shift to the server approach created the need for additional support for privacy management. This was achieved by the use of filters that determined which classes of evidence were available to which applications and which resolvers could be used by them. If the user allowed general access to an application, it could have all evidence and make its own interpretation of that evidence. On the other hand, a very restricted application may only be allowed access via one resolver.

Fink and Kobsa [24] discuss the benefits of user modeling servers that have:

> Up-to-date user information for holistic personalization; Synergistic effects with respect to acquisition and usage of user information; Low redundancy with respect to application and domain independent information; Low redundancy with respect to stereotypes and user group models; Increased security; Increased support for the holistic design, acquisition, and maintenance of user models.

As discussed earlier, Kobsa [49] surveyed characteristics of academic and commercial user modeling shells and identified requirements for future servers for reuse of user models such as is needed for mobile and pervasive settings.

Work in user modeling servers started in the mid-1990s as generic systems and during the 2000s changed to deal with provision of user modeling data to variety of applications that need personal information, as can be seen in the work of Kay et al. [47], Fink and Kobsa [25], Carmichael et al. [18], Kobsa and Fink [50] and others. However, many issues remained unresolved, including the need for applications to adapt to the server's user modeling representation. This seems to be a major constraint since there is no active server that systems can use and so recommender systems and other personalized service providers produce their own user modeling mechanisms.

4.3 User Modeling Mediation, Interoperability and Hybridization

The ability to integrate fragments of existing user models is a possible solution for bootstrapping a user model when there is no prior personal information, but partial information may be requested from other systems. Berkovsky et al. [6] coined the term "user model mediation". The basic idea is that in many cases fragments of user models are available, in different representations for the same domain, or from different domains or even from different contexts, hence there is a need to define methods for translating or mediating them across representations, domains and contexts. They suggested and demonstrated several such techniques for transferring data from a collaborative to a content based approach and from a case-based to a content-based approach and discussed the more complicated situations (cross-domain and cross-context), suggesting future research in addressing these issues.

Carmagnola and Dimitrova [16] and Walsh and Wade [86] discuss user modeling interoperability – an approach that differs from mediation in the way it integrates user modeling data. Carmagnola and Dimitrova [16] suggest that "evidence" of user modeling data is collected from various sources and then a domain ontology is used to reason and integrate the evidence for creating an ad-hoc user model. Walsh and Wade, on the other hand, suggest an approach that allows automatic translation of user modeling data, following initial mapping between different models/representations/systems. In such a scenario, an administrator performs an initial mapping and then, as user models are updated and information is needed, up-to-date information may become available for any application that needs it, based on the initial mapping. Walsh and Wade suggested it for learners' models, where once mapped, ongoing relatively long time interaction can benefit from the initial manual mapping.

Vassileva et al. [85] suggest an approach of match makers – broker agents that are able to find the relevant user modeling information needed for a personalization task among a group of specialized user modeling agent.

Hybridization of user modeling techniques has less to do with user modeling interoperability and reuse and more with combining the benefits, and avoiding the limitations, of individual techniques. Notably, using complimentary techniques may overcome the cold start problem. This is relevant to ubiquitous user modeling – when there is a need to construct, from scratch, an ad-hoc user model. Hence, hybrid approaches deserve mention in this context as well (this approach was already introduced earlier, and for detailed discussion see Ref. [13]).

4.4 Using Social Networks Data for Ubiquitous User Modeling

Social networks offer an opportunity for systems providing personalized service to their users to gain publicly available personal information for bootstrapping a user model. This is extremely important in the ubiquitous computing scenario. Using the API of social networks, systems can request personal information and by applying a suitable mediation mechanism, convert it to their domain and internal representation. This was explored for several different social networking sites with particular care to ensure users can understand the system [53, 54]. There is considerable amount of work exploring the potential of social networks data for user modeling. Liu et al. [58] were among the first who tried to extract personal information available in social networks and apply it to personalization tasks in recommender systems. They followed a five-steps process for mining and weaving the taste fabric from social network profiles: (1) acquiring the profiles from social networking sites, (2) segmentation of the natural language profiles to produce a bag of descriptors of user characteristics, (3) mapping the natural language fragment descriptors into formal ontology, (4) learning the correlation matrix, and (5) discovering taste neighborhoods via morphological opening and labeling the network topology. By doing this it is possible to construct multi-faceted user profiles and find neighborhood of similar users over several domains, hence to enable cross-domain recommendations. They evaluated their approach by mining data from two online social networks and using it for recommendation in various combinations of their approach, including one that resembles classical collaborative filtering and showed that the use of their "taste fabric" provides better results. Seth and Zhang [74] used social networks data for building a user profile to be used for news stories recommendation. The main benefit from the ubiquitous user modeling point of view is that this information may be publicly available and accessible to the environment for bootstrapping an ad-hoc user model on the fly. The use of social networks for user modeling is a new dynamic and evolving area of research, especially due to easy access to freely available personal information in these networks (see also Refs. [76, 77, 80, 92, 95] and many more).

4.5 Mobile User Modeling

In ubiquitous computing, particularly in the case of the mobile user who needs a personalized service, we need to tackle the challenge of making sure that existing user models are available to the environment. Uhlmann and Lugmayr [82] describe the motivation for mobile profiles and provide an overview of the challenges and recent work on mobile personalization. To date, most of the personalized mobile applications developed have relied on server side user modeling, with the user model residing on the server while the user interacts with the system via a mobile device that sometimes captures also the user's context.

This mobile scenario calls for some additional tools beyond the use of a centralized user model server that may not be available/reachable every time the user needs it and everywhere. A possible solution is client-side personalization. In this case, the environment has to interact with the user (or the user's agent) to define the available services and the required personal data needed to drive them. For privacy protection, the user should be able first to decide what information she is willing to provide in return for the potential value of the personalized service. Client side personalization introduces new challenges for user modeling. First, there is a need to communicate with the environment, in order to negotiate and exchange user modeling data. Initial work in that area includes User ML, a user modeling language developed by Heckmann and Kruger [33]; this provided a first step towards bridging the gap between user modeling servers and occasional clients. Then there is a need to have a mobile user model, stored and maintain on a limited mobile device (both in storage and computing power). Heckmann and Kruger [33] provided an initial idea by pointing and referring to GUMO [34] – so the user model is a partial overlay on GUMO, which may help standardize the representation and interaction.

Additional work targeted specifically at personalization in mobile scenarios has been the focus of several researches. Myrhaug et al. [62] and Göker et al. [28] demonstrated a system that provided personalized and context aware information to users in ubiquitous computing environment by using special “context tags”. The tags provided relevant information to users in their vicinity, while the context middleware on the device filtered the information based on the context of the user that included personal characteristics. In this case, the mobile context involved an integrated system, so avoiding some of the challenges of ubiquitous user modeling we have identified earlier. Quite a few similar systems appeared, providing personalized service to the user on the go. However, such stand alone systems do not provide any real solution for ubiquitous computing. Gonzáles et al. [29] went a step forward in their proposal for a generic multi-agent based user modeling framework. A user modeling agent may reside on a user mobile device or on a desktop and the user personal characteristics and the user modeling parameters can be mapped a priori to specific user modeling requirements for specific domains, represented by specific agents. Hence, whenever a service from an application is required, the application agent interacts with the user model agent to get the relevant information as needed.

Kuflik and Poteriaykina [52] proposed a user model on a personal device, where, the environment interacts with a personal agent on the device to provide a personalized service. The environment also negotiates with the agent to acquire the user modelling data needed/available for personalization. The mobile device must provide the data in the format required by the environment. The proposal combines a mobile personal server with a user model mediator and UserML based communication language for enabling exchange of user modelling in ubiquitous computing. Gerber et al. [26] created a somewhat different approach – PersonisJ a personal user model stored on the phone and based on Personis [47]. In their approach, the mobile phone uploads an application which provides the personalized service on the phone, with security and privacy controls ensuring that the user model remains on the phone; the application cannot send it off the phone. However, PersonisJ requires that the application be able to interpret and use the user modelling ontology and data.

4.6 A Word About Context Awareness

Context awareness plays a major role in ubiquitous computing. Notably, context includes the location and time, as well as other arbitrary information describing the user’s current situation. Obviously, this can have an impact on personalization as well, meaning that the personalization should take account of it, regardless of the personalization approach or technique employed [79]. Even though context awareness is tightly coupled with user modeling, as discussed by Jameson and Krüger [41], context awareness is out of scope for this chapter. The reader is referred to a vast body of work on context awareness in ubiquitous or pervasive computing. One outstanding example is Dey et al. [19] who defined a generic framework for modeling and using contextual information. Other context aware surveys include [5, 36, 42, 78].

5 Discussion and Summary

Jameson and Krüger [41] implicitly noted the relationship between user modeling and ubiquitous computing. However, they correctly noted:

> We believe that the field of user modeling can contribute significantly to the enhancement of the effectiveness and usability of ubiquitous computing systems. In turn, the field of ubiquitous computing, by building the technological basis for mobile and migrating systems, is offering the user modeling community opportunities to apply their methods to novel types of systems, extending the methods themselves in the process.

However, so far very little research has taken this opportunity. Most solutions suggested so far have focused on narrow solutions. The main challenge presented by ubiquitous computing is the notion of "context" of the user that is complicated and dynamically changing and must be taken into consideration in addition to longer term, more stable user characteristics.

This chapter has provided a brief introduction to user modeling and then introduced ubiquitous user modeling, with its unique characteristics and challenges. We have outlined various partial solutions that exist or that are the subject of current research and offer promise for ubiquitous user modeling. It aimed to introduce the challenges as well as state-of-the-art partial solutions of ubiquitous user modeling. While there is a great variety of possible solutions, as briefly surveyed above, the main challenge is still unsolved – how to provide a personalized service for a first time user in ubiquitous computing? Addressing this challenge requires mutual effort of user modeling researchers and researchers working on ubiquitous computing – they must provide an integrated solution for personalization in ubiquitous computing, as so clearly described by Jameson and Krüger [41].

Ubiquitous display environments constitute a special case in ubiquitous computing because users approach and interact with situated public displays, seeking to benefit from a personalized service. To achieve this, we need to find ways to enable the environment to seamlessly acquire their relevant personal information (while respecting their privacy policies) and use it to provide a service matching their needs and preferences, without forcing them to explicitly interact to provide information to bootstrap the user model. Hence interaction between the environment and a mobile device seems the most promising approach for negotiating the service and the personal information. To achieve this, integration of the above-mentioned techniques is needed as well as addressing challenges related to user modeling representation – what information is available in a user model and how it is represented? How this information is made available to the environment, including the interaction between the user model and the environment are required. These are still yet to be resolved issues.

References

1. Abowd, G. D.: 1999, Software engineering issues for ubiquitous computing. In Proceedings of the 21st international Conference on Software Engineering (Los Angeles, California, United States, May 16–22, 1999). ICSE '99. ACM, New York, NY, 75–84.
2. Abowd, G. D., and Mynatt, E. D.: 2000, Charting past, present, and future research in ubiquitous computing. ACM Transactions on. Computer.-Human. Interaction. 7(1), 29–58.
3. Agnar, A., and Plaza, E.: 1994, Case-Based Reasoning: Foundational Issues, Methodological Variations, and System Approaches, Artificial Intelligence Communications 7(1), 39–59.
4. Assad, M., Carmichael, D., Kay, J., and Kummerfeld, B.: 2007, PersonisAD: Distributed, Active, Scrutable Model Framework for Context-Aware Services. Pervasive 2007, Toronto, Ontario, Canada, Springer, 4480, 55–72.
5. Baldauf, M., Dustdar, S., and Rosenberg, F.: 2007, A survey on context-aware systems. International Journal of Ad Hoc Ubiquitous Computing. 2(4), 263–277.
6. Berkovsky, S., Kuflik, T., and Ricci, F.: 2008, Mediation of user models for enhanced personalization in recommender systems. User Modeling And User-Adapted Interaction. 18 (3), 245–286.
7. Billsus, D., and Pazzani, M. J.: 2000, User modeling for adaptive news access. User Modeling and User-Adapted Interaction 10(2–3), Special Issue on Deployed User Modeling, 147–180.
8. Bohrer, K., and Holland, B.: 2000, Customer profile exchange (cpexchange) specification. http://www.cpexchange.org/
9. Brusilovsky, P.: 1996, Methods and techniques of adaptive hypermedia. User Modeling and User-Adapted Interaction 6(2–3), 87–129.
10. Brusilovsky, P., and Maybury, M. The Adaptive Web.: 2002, Communications of the ACM, 2002.
11. Brusilovsky, P., Sosnovsky, S., and Yudelson, M.: 2005, Ontology-based Framework for User Model Interoperability in Distributed Learning Environments. In G. Richards (ed.), Proceedings of World Conference on E-Learning in Corporate, Government, Healthcare, and Higher Education 2005, 2851–2855. Chesapeake, VA: AACE.
12. Burke, R.: 1999, Integrating Knowledge-based and Collaborative-filtering Recommender Systems. In Proceedings of the Workshop on AI and Electronic Commerce, at the AAAI 99 conference.
13. Burke, R.: 2000, Knowledge-based Recommender Systems, in A. Kent (ed.), Encyclopedia of Library and Information Systems. 69, Supplement 32.
14. Burke, R.: 2002. Hybrid recommender systems: Survey and experiments. User Modeling and User-Adapted Interaction, 12(4):331–370.
15. Cardoso, R. S., and Issarny, V.: 2007, Architecting Pervasive Computing Systems for Privacy: A Survey. In Proceedings of the Sixth Working IEEE/IFIP Conference on Software Architecture (January 06–09, 2007). WICSA. IEEE Computer Society, Washington, DC, 26.
16. Carmagnola, F., and Dimitrova, V.: 2008, An Evidence-Based Approach to Handle Semantic Heterogeneity in Interoperable Distributed User Models. In Proceedings of the 5th international Conference on Adaptive Hypermedia and Adaptive Web-Based Systems (Hannover, Germany, July 29–August 01, 2008). W. Nejdl, J. Kay, P. Pu, and E. Herder, Eds. Lecture Notes In Computer Science, vol. 5149. Springer-Verlag, Berlin, Heidelberg, 73–82.
17. Carmagnola, F., Cena, F., Console, L., Cortassa, O., Gena, C., Goy, A., Torre, I., Toso, A., and Vernero, F.: 2008, Tag-based user modeling for social multi-device adaptive guides. User Modeling and User-Adapted Interaction 18(5), 497–538.
18. Carmichael, D. J., Kay, J., and Kummerfeld, B.: 2005, Consistent Modeling of Users, Devices and Sensors in a Ubiquitous Computing Environment. User Modeling and User-Adapted Interaction 15, 3–4, 197–234.
19. Dey, A. K., Abowd, G. D., and Salber, D.: 2001. A conceptual framework and a toolkit for supporting the rapid prototyping of context-aware applications. Hum.-Comput. Interact. 16, 2 (Dec. 2001), 97–166.

20. Denaux, R., Dimitrova, V., and Aroyo, L.: 2004, Interactive Ontology-Based User Modeling for Personalized Learning Content Management, SW-EL'04: Semantic Web for E-Learning, workshop co-located with, AH 2004: International Conference on Adaptive Hypermedia and Adaptive Web-Based Systems, Eindhoven, The Netherlands, August 23–26.
21. Dolog, P., and Nejdl, W.: 2003. Challenges and benefits of the semantic web for user modelling. In Proc. of AH2003 – Workshop on Adaptive Hypermedia and Adaptive Web-Based Systems, WWW2003 Conference, Hypertext'03 Conference, User Modelling Conference 2003, Budapest, Hungary, Nottingham, UK, Johnstown, PA, USA, May 2003.
22. Dolog, P., Henze, N., Nejdl, W., and Sintek, M.: 2004, The Personal Reader: Personalizing and Enriching Learning Resources using Semantic Web Technologies. In Proc. of AH2004 – International Conference on Adaptive Hypermedia and Adaptive Web-Based Systems, August, 2004, Eindhoven, The Netherlands. Springer Verlag
23. Endres, C., and Butz, A. "A Survey of Software Infrastructures and Frameworks for Ubiquitous Computing", Mobile Information Systems Journal, 1(1), Jan–Mar 2005.
24. Fink, J., and Kobsa, A.: 2000, A Review and Analysis of Commercial User Modeling Servers for Personalization on the World Wide Web. International Journal on User Modeling and User-Adapted Interaction, 10(2–3), 209–249.
25. Fink, J., and Kobsa, A.: 2002. User Modeling for Personalized City Tours. Artificial Intelligence. Review 18(1), 33–74.
26. Gerber, S., Pink, G., Fry, M., Kay, J., Kummerfeld, B., and Wasinger, R.: 2010, PersonisJ: mobile, client-side user modelling, TR648, School of Information Technologies, University of Sydney.
27. Goldberg, D., Nichols, D., Oki, B. M., and Terry, D.: 1992, Using collaborative filtering to weave an information tapestry. Commun. ACM 35, 12, 61–70.
28. Göker, A., Watt, S., Myrhaug, H. I., Whitehead, N., Yakici, M., Bierig, R., Nuti, S. K., and Cumming, H.: 2004. An ambient, personalised, and context-sensitive information system for mobile users. In Proceedings of the 2nd European Union Symposium on Ambient intelligence (Eindhoven, Netherlands, November 08–10, 2004). EUSAI '04, vol. 84. ACM, New York, NY, 19–24.
29. González, G., Angulo, C., López, B., and de la Rosa, J. L.: 2005, Smart User Models for Ambient Recommender Systems, in Ambient Intelligence and (Everyday) Life, eds., Y. Cai. and J. Abascal, 113–122, San Sebastian, Spain, (July 2005). University of the Basque Country.
30. Gross, T.: 2008, Cooperative ambient intelligence: towards autonomous and adaptive cooperative ubiquitous environments. Int. Journal. On Autonomous. Adaptive. Communication. Systems. 1(2), 270–278.
31. Hanani, U., Shapira, B., and Shoval, P.: 2001, Information Filtering: Overview of Issues, Research and Systems. User Modeling and User Adapted Interactions, 11(3), 203–259.
32. Hatala, M., and Wakkary, R.: 2005, Ontology-Based User Modeling in an Augmented Audio Reality System for Museums. User Modeling and User-Adapted Interaction 15(3–4),339–380.
33. Heckmann, D., and Kruger, A. (2003) "A User Modeling Markup Language (UserML) for Ubiquitous Computing". In *9th International Conference on User Modeling (UM'2003)*, Pittsburgh, June, pp. 393–397
34. Heckmann, D.: 2005, Ubiquitous User Modeling, Ph.D. thesis, Computer Science Department, Saarland University, Germany.
35. Henricksen, K., Indulska, J., and Rakotonirainy, A.: 2001, Infrastructure for pervasive computing: Challenges. In GI Jahrestagung (1), 214–222.
36. Henricksen, K., Indulska, J., McFadden, T., and Balasubramaniam, S.: 2005, Middleware for distributed context-aware systems. In Proc. of On the Move to Meaningful Internet Systems, LNCS 3760, 846–863.
37. Henze, N., and Kriesell, M.: 2004, Personalization functionality for the semantic web: Architectural outline and first sample implementation. In Proceedings of the 1st International Workshop on Engineering the Adaptive Web (EAW 2004), co-located with AH 2004, Eindhoven, The Netherlands.

38. Henze, N., Krause, D.: 2006, Personalized access to web services in the semantic web. In: Cruz, I., Decker, S., Allemang, D., Preist, C., Schwabe, D., Mika, P., Uschold, M., Aroyo, L. (eds.) ISWC 2006. LNCS, vol. 4273, Springer, Heidelberg.
39. Iqbal, R., Sturm, J., Kulyk, O., Wang, J., and Terken, J.: 2005. User-centred design and evaluation of ubiquitous services. In Proceedings of the 23rd Annual international Conference on Design of Communication: Documenting & Designing For Pervasive information. Coventry, United Kingdom, September 21–23.
40. Izadi, S., Coutinho, P., Rodden, T., and Smith, G.: 2002, The fuse platform: Supporting ubiquitous collaboration within diverse mobile environments. Automated Software Engineering, 9(2), 167–186.
41. Jameson, A., and Krüger, A.: 2005. Preface to the Special Issue on User Modeling in Ubiquitous Computing. User Modeling and User-Adapted Interaction 15(3–4), 193–195.
42. Kjær, K. E.: 2007, A survey of context-aware middleware. In Proceedings of the 25th Conference on IASTED international Multi-Conference: Software Engineering (Innsbruck, Austria, February 13–15, 2007). W. Hasselbring, Ed. IASTED International Multi-Conference: Software Engineering. ACTA Press, Anaheim, CA, 148–155.
43. Kay, J.: 1990, um: a user modelling toolkit, Second International User Modeling Workshop, Hawaii, 251–261.
44. Kay, J.: 1994. Lies, damned lies and stereotypes: pragmatic approximations of users, Kobsa, A and D Litman (eds.), Proceedings of the Fourth International Conference on User Modeling, UM Inc, 175–184.
45. Kay, J.: 1995. The um toolkit for cooperative user modeling, User Modeling and User-Adapted Interaction 4(3), 149–196.
46. Kay, J.: 1999. Ontologies for reusable and scrutable student models, Mizoguchi, R, (ed) AIED Workshop W2: Workshop on Ontologies for Intelligent Educational Systems, 72–77.
47. Kay, J., Kummerfeld, B., and Lauder, P.: 2002, Personis: A server for user models. In: AH'02: Proceedings of Adaptive Hypermedia and Adaptive Web-Based Systems, Springer-Verlag, London, UK, 203–212.
48. Kobsa, A.: 1995, Editorial. Using Modeling and User-Adapted Interaction 4(2), Special Issue on User Modeling Shell Systems, iii^v.A.
49. Kobsa. A.: 2001, Generic User Modeling Systems. User Modeling and User-Adapted Interaction 11(1–2), 49–63.
50. Kobsa, A., and Fink, J.: 2006, An LDAP-based User Modeling Server and its Evaluation. User Modeling and User-Adapted Interaction 16(2), 129–169.
51. Kobsa, A., and Wahlster, W.: 1989, User models in dialog systems. Springer-Verlag.
52. Kuflik, T., and Poteriaykina, K.: 2009, User Model on a Key. In Proceedings of Hypertext 2009, Torino, Italy, June 29th–July 1st 2009, 371–372.
53. Kyriacou E. D.: 2009, Enriching Lifelong User Modelling with the Social e-Networking and e-Commerce "Pieces of the Puzzle". In: First and Seventeenth International Conference on User Modeling, Adaptation, and Personalization (UMAP2009)
54. Kyriacou, D., Davis, H., and Tiropanis, T.: 2009, Evaluating Three Scrutability and Three Privacy User Privileges for a Scrutable User Modelling Infrastructure, In: First and Seventeenth International Conference on User Modeling, Adaptation, and Personalization (UMAP2009) 22–26.
55. Lyytinen, K., and Yoo, Y. (eds.): 2002. Communications of the ACM 45 (12): 62–96.
56. Langheinrich, M.: 2001, Privacy by design – principles of privacy-aware ubiquitous systems. In Proceedings of UbiComp 2001, 273–291, Atlanta, GA, USA.
57. Lehikoinen, J. T., Lehikoinen, J., and Huuskonen, P.: 2008. Understanding privacy regulation in ubicomp interactions. *Personal Ubiquitous Computing* 12(8), 543–553.
58. Liu, H., Maes, P., and Davenport, G.: 2006, Unraveling the taste fabric of social networks. International Journal on Semantic Web and Information Systems, 2(1), 42–71.
59. Malone, T., Grant, K., Turbak, F., Brobst, S., and Cohen, M.: 1987, intelligent information sharing systems. Communications of the ACM 30(5), 390–402.

60. McCarthy, J.: 2001, Active environments: Sensing and responding to groups of people. Personal and Ubiquitous Computing, 5(1), Available at http://www.inf.ethz.ch/vs/events/dag2001/.
61. Mehta, B., Nieder'ee, C., Stewart, A., Degemmis, M., Lops, P., and Semeraro. G.: 2005, Ontologically-enriched unified user modeling for cross-system personalization. In User Modeling, 119–123.
62. Myrhaug, H., Whitehead, N., Goker, A., Faegri, T. E., and Lech, T. C.: 2004, AmbieSense – A System and Reference Architecture for Personalised Context-Sensitive Information Services for Mobile Users. 2nd European Symposium on Ambient Intelligence EUSAI 2004, Eindhoven, Netherlands, LNCS Volume 3295/2004 Springer-Verlag 327–338.
63. Mostefaoui, G. K., Pasquier-Rocha, J., and Brezillon, P.: 2004, Context-Aware Computing: A Guide for the Pervasive Computing Community. In Proceedings of the IEEE/ACS international Conference on Pervasive Services (July 19–23, 2004). ICPS. IEEE Computer Society, Washington, DC, 39–48.
64. Niemelä, E., and Latvakoski, J.: 2004. Survey of requirements and solutions for ubiquitous software. In Proceedings of the 3rd international Conference on Mobile and Ubiquitous Multimedia (College Park, Maryland, October 27–29, 2004). MUM '04, vol. 83. ACM, New York, NY, 71–78.
65. Niu, W. T., and Kay, J.: 2010, PERSONAF: Framework for personalized ontological reasoning in pervasive computing. User modeling and User-Adapted Interaction: the Journal of Personalization Research, 20(1) 1–40.
66. Pham, T., Schneider, G., and Goose, S.: 2000, A situated computing framework for mobile and ubiquitous multimedia access using small screen and composite devices. In Proceedings of the Eighth ACM international Conference on Multimedia (Marina del Rey, California, United States). MULTIMEDIA '00. ACM, New York, NY, 323–331.
67. Razmerita, L., Angehrn, A., and Maedche, A.: 2003, Ontology based user modeling for Knowledge Management Systems, Proceedings of the User Modeling Conference, Pittsburgh, USA, Springer Verlag, 213–217.
68. Ricci, F., and Werthner, H.: 2002, Case base querying for travel planning recommendation. Information Technology and Tourism, 3(3/4), 215–226.
69. Rich, E.: 1983, Users are Individuals: individualizing user. International Journal of Man-machine studies, 18(3), 199–214.
70. Saha, D., and Mukherjee, A.: 2003, Pervasive computing: a paradigm for the 21st century. Computer, 36(3), 25–31.
71. Sarwar, B., Karypis, G., Konstan, J., and Riedl, J. 2001. Item-based collaborative filtering recommendation algorithms. In Proceedings of the 10th international conference on World Wide Web (WWW '01). ACM, New York, NY, USA, 285–295.
72. Satyanarayanan, M.: 2002, Pervasive computing: vision and challenges. Personal Communications, IEEE, 8(4), 10–17.
73. Self, J.: 1990, Bypassing the intractable problem of student modelling, Intelligent Tutoring System: At the Crossroads of Artificial Intelligence and Education, 107–123.
74. Seth, A., and Zhang, J.: 2008, A Social Network Based Approach to Personalized Recommendation of Participatory Media Content. Proc. ICWSM'08. Seattle, WA.
75. Slay, H., and Thomas, B.: 2006, Interaction and visualisation across multiple displays in ubiquitous computing environments. In Proceedings of the 4th international Conference on Computer Graphics, Virtual Reality, Visualisation and interaction in Africa (Cape Town, South Africa, January 25–27, 2006). AFRIGRAPH '06. ACM, New York, NY, 75–84.
76. Song, X., Tseng, B., Lin, C., and Sun, M.: 2006. Personalized recommendation driven by information flow. SIGIR.
77. Stan, J., Egyed-Zsigmond, E., Joly, A. and Maret, P. "A User Profile Ontology For Situation-Aware Social Networking," 3rd Workshop on Artificial Intelligence Techniques for Ambient Intelligence (AITAmI2008), Jul. 2008.

78. Strang, T., and Linnhoff-Popien, C.: 2004, A context modeling survey. In 1st Int. Workshop on Advanced Context Modelling, Reasoning and Management.
79. Sutterer, M., Droegehorn, O., and David, K.: 'Upos: 2008, User profile ontology with situation-dependent preferences support', Proceedings of the First International Conference on Advances in Computer-Human Interaction, ACHI 2008. February 10–15, 2008 – Sainte Luce, Martinique, 230–235.
80. Torre, I.: 2009, Adaptive systems in the era of the semantic and social web, a survey. User Modeling and User-Adapted Interaction 19(5), 433–486.
81. Tutzschke, J., and Zukunft, O.: 2009, FRAP: a framework for pervasive games. In Proceedings of the 1st ACM SIGCHI Symposium on Engineering interactive Computing Systems (Pittsburgh, PA, USA, July 15–17, 2009). EICS '09. ACM, New York, NY, 133–142.
82. Uhlmann, S., and Lugmayr, A.: 2008, Personalization algorithms for portable personality. In Proceedings of the 12th international Conference on Entertainment and Media in the Ubiquitous Era (Tampere, Finland, October 07–09, 2008). MindTrek '08. ACM, New York, NY, 117–121.
83. van Elst, L., Abecker, A., and Maus. H.: 2001, Exploiting User and Process Context for Knowledge Management Systems. Workshop on User Modeling for Context-Aware Applications at the 8th Int. Conf. on User Modeling, July 13–16, 2001, Sonthofen, Germany.
84. Vassileva, J.: 1996, A task-centered approach for user modeling in a hypermedia office documentation system, User Modeling and User-Adapted Interaction, 6, 185–223.
85. Vassileva, J., Mccalla, G., and Greer, J.: 2003. Multi-Agent Multi-User Modeling in I-Help. User Modeling and User-Adapted Interaction 13(1–2), 179–210.
86. Walsh, E., Wade, V.:2009, Lowering the Barriers to User Model Interoperability, Ubiquitous User Modeling in proceedings of the Workshop at the Conference on User Modeling, Adaptation, Personalization (UMAP), Trento, Italy, 22–26 June 2009. 44–47.
87. Waller, V., and Johnston, R. B.: 2009. Making ubiquitous computing available. Communication of the. ACM 52(10), 127–130.
88. Weiser, M.: 1991, The computer for the 21st century, Scientific American, 3(265):94–014.
89. Weiser, M.: 1993, Some computer science issues in ubiquitous computing. Communications of the ACM 36(7), 75–84.
90. Weiβenberg, N., Voisard, A., and Gartmann, R.: 2004. Using ontologies in personalized mobile applications. In Proceedings of the 12th Annual ACM international Workshop on Geographic information Systems (Washington DC, USA, November 12–13, 2004). GIS '04. ACM, New York, NY, 2–11.
91. Wilensky, R., Arens, Y., and Chin, D.: 1984, Talking to UNIX in English: an overview of UC. Communications of the ACM 27(6), 574–593.
92. Yang, J., Wang, J., Clements, M., Pouwelse, J., de Vries, A. P., and Reinders, M.: 2007. An epidemic-based p2p recommender system. SIGIR-WS Large Scale Distributed Systems.
93. Yimam-Seid, D., and Kobsa, A.: 2003, Expert Finding Systems for Organizations: Problem and Domain Analysis and the DEMOIR Approach. Journal of Organizational Computing and Electronic Commerce 13(1), 1–24.
94. Yovanof, G. S., and Hazapis, G. N.: 2009. An Architectural Framework and Enabling Wireless Technologies for Digital Cities & Intelligent Urban Environments. Wireless. Personal. Communication. 49(3), 445–463.
95. Yu, B., and Singh, M.: 2003. Searching social networks. In Proceedings of the second international joint conference on Autonomous agents and multiagent systems (AAMAS '03). ACM, New York, NY, USA, 65–72.
96. Yudelson, M., Gavrilova, T., and Brusilovsky. P.: 2005, Towards user modeling metaontology. In L. et al. Ardissono, editor, 10th Int. Conf. on User Modeling, UM'05, 448–452, Edinburgh, Scotland, UK.
97. Zhang, F., Song, Z., and Zhang, H.: 2006. Web Service Based Architecture and Ontology Based User Model for Cross-System Personalization. In Proceedings of the 2006 IEEE/WIC/ACM international Conference on Web intelligence (December 18–22, 2006). Web Intelligence. IEEE Computer Society, Washington, DC, 849–852.