MUSE: A Multidimensional Semantic Environment for Adaptive Hypermedia Systems

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Abstract

This paper proposes a semantic framework built on multidimensional ontological planes for the design of adaptive systems. The core of the framework is composed by three matrices whose different planes contain the ontological representation of different types of knowledge. On these planes we represent user features, her actions, context, device, content domain, adaptation goals and methods. The join between planes allows us to represent semantic rules for inferring new user features and to define adaptation strategies. We exploit OWL (Ontology Web Language) to represent taxonomic knowledge and SWRL (Semantic Web Rule Language) for rules. The framework presents a new approach to build adaptive hypermedia systems that support interoperability.

1 Introduction

Adaptive hypermedia systems typically reflect some features of the user in the user model and apply this model to adapt various aspects of the system (content, interface, navigation) to the user. Current adaptive systems also take into account other features, besides the user model, such as the context of interaction and the device. In the last years adaptive systems have started to include semantic web methodologies to represent the knowledge base which they are based on.

Usually the corpus of the documents and services the system can adapt is already known at the design time and can be defined as a *closed corpus of adaptation* [Brusilovsky , 1996]. The application of Semantic Web technologies to adaptive systems and the use of shared ontologies and metadata to describe resources can contribute to extend the closed corpus to an *open corpus of adaptation.* Thus, external documents and resources, which are semantically annotated, can be considered during the adaptation to the users. Furthermore, representing the user model with a semantic formalism and shared ontologies can be the base for building a *user model server*: a server that enables the sharing of knowledge about user modeling and adaptation strategies across applications [Kay et al., 2002]. Different adaptive systems can query the same user model server and share the common knowledge.

This paper describes an ontology-based framework which aims at providing:

- a methodological approach for the design and development of adaptive hypermedia systems,
- shared ontologies and reasoning strategies (generated by the framework and semantically represented), which can be accessed and re-used by other applications.

In particular the framework manages two types of adaptation knowledge: *i*)knowledge regarding which features of the system have to be adapted and which dimensions (user, context, device, etc.) have to be taken into account to perform adaptation; *ii*)knowledge regarding adaptation strategies and rules for relating user features to other user features, extending the user model and inferring new knowledge from the available one.

We represent (i) the declarative descriptions of adaptve system dimensions with ontologies expressed in a standard semantic markup language for the Semantic Web, OWL[1], and (ii) the inference rules with SWRL[2], a proposal for a semantic rule language.

2 The choice of a semantic knowledge representation

As mentioned in the introduction, most adaptive hypermedia systems are based on adaptation rules that personalize the application, taking into account a user model, a domain model and, more and more frequently, a device and a context model. Several works in this field exploit ontologies, to describe the domain model, in order to give a meaning to the resources that some adaptation rules will personalize with respect to the user model. More recently, other works adopted ontologies to represent user models, devices features, context of interaction [Dolog et al., 2004],[Heckmann and Krueger, 2003]. On the contrary, the semantic representation of reasoning strategies is still little addressed.

In our project we semantically handle both ontologies and reasoning strategies. As far as ontologies are concerned, we use them since they allow to represent and share conceptualizations of a certain knowledge domain [Gruber, 1993] and contain a large set of pertinent concepts (entities, attributes) and the relations among them (such as IS_A, PART_OF, PORPUSE_OF).

OWL is the formalism we chose to express ontologies. It is the new standard ontology language of the Semantic Web, defined by W3C and developed as a revision of the

[1] http://www.w3.org/TR/owl-features/
[2] http://www.w3.org/Submission/SWRL/

previous DAML+OIL[3] and having a set of powerful primitives, mostly derived from description logic, it provides more expressive power than RDF and RDF schema.

Although ontologies have a set of basic implicit reasoning mechanisms derived from the description logic which they are typically based on (such as classification, subsumption, satisfiability, instance checking), they need rules to express implicit relationships, to make further inferences and to create useful relations on the represented pieces of information.
Thus, *ontologies* require a rule system to derive/use further information that cannot be captured by them and *rule systems* require ontologies in order to have a shared definition of the concepts and relations mentioned in the rules. Rules also allow adding expressiveness to the representation formalism, reasoning on the instances, and they can be orthogonal to the description logic on which ontologies are based on. Moreover, ontologies and rules can provide humans (and machines) with rational explanations of system behaviour, thus improving their trust on the system. In the specific case of the Semantic Web, this is a relevant aspect for the so-called *proof layer*, which involves the "deductive process as well as the representation of proofs in Web Languages and proof validation" [Antoniou and Van Harmelen, 2004]. In this way, the proof presentation can be considered as a way for humans/machines to retrace the derivation of answers. To achieve these goals, rules have to be expressed using semantic and standard formalisms as well as ontologies, moving from the idea that an open format supports scrutability.
In our project, we exploit SWRL, a Semantic Web Rule Language combining OWL and RuleML[4]. In particular, SWRL is a combination of OWL Description Logic, OWL Lite and the Unary/Binary Datalog RuleML, and extends the set of OWL axioms to include Horn-like rules. Like RuleML, SWRL allows interoperability with major rules systems (commercial and not) such as CLIPS, JESS.

Summarizing, a semantic representation of rules has different purposes, in particular: *i*) it enables knowledge sharing between software agents and human designers; *ii*) it allows to compare and evaluate rules, detect incompatibilities, validate or possibly refuse them both in the design phase and in the execution phase; *iii*) in the field of adaptive systems, it allows to give explanations about the generation of inferences of user features, of the system adaptive behaviour and of its adaptation strategies.

3 Description of the framework

The framework we propose aims at semantic representation of knowledge bases and rules, and their implementation in adaptive hypermedia systems based on symbolic reasoning. In addition to the above reasons, the choice of using a semantic formalism in order to define the framework arises from the evidence that user features are common to different applications and, if semantically described, they can be shared among them (consider for example the feature "*user familiarity with the system"*: it is used by almost all adaptive systems). Defining these dimensions once for all represents an interesting opportunity in terms of reduced design costs and optimization of results. Moreover, the ontological representation of user, device, context and domain models also arises from the diffusion of this kind of ontologies on the web (the last one in particular), and the possibility to link such ontologies and integrating them with semantic web technologies and Web Services[5].

For the definition of this semantic framework we developed a multidimensional model composed of different planes (see for a visual representation of the model). They allow us to organize different aspects of ontological information: each plane contains the ontological representation of a specific type of knowledge. In particular we have:

- user model ontology
- user actions ontology
- domain ontology
- device ontology
- context ontology
- adaptation goals ontology
- adaptation methods and techniques ontology

Regarding rules, the framework semantically represents and manages the typical and relevant rules in adaptive hypermedia systems:

- *user modeling rules* that add knowledge about a user by inferring new user features from other features,
- *adaptation rules* that can be furtherly divided into two different types: *coarse adaptation rules*, that define the strategies of adaptation, given the adaptation goals, and *detailed adaptation rules*, that select specific adaptation techniques, taking into account user features, domain, context and the device in use.

Being a framework, the ontologies on the planes have to be independent from a particular application (although they derive from analysis of different adaptive hypermedia systems) and modular, so they can be reused among different domains and applications. The modularity is obtained through the use of multiple lighter weight ontologies rather than a heavy monolithic one and the reusability can be reached through the separation, as seen above, in different ontologies (of the model of the user, of the device, of the domain). In some planes we exploit and extend shared ontologies (in particular CC/PP[6] for the device, Ubisword[7] for the user and the context features, the Open Directoy Project for the domain[8]), since they are easier to map, public available and better known.
Each ontology is defined at *different levels of abstraction*: at the first level there is the definition of general concepts. For example, for the *domain ontology*, the first level includes macro domains such as tourist domain, financial domain, e-learning domain; for the *adaptation-goals ontology*, the first level specifies general goals such as: inducing/pushing; informing, explaining, suggest-

[3] http://www.w3.org/TR/daml+oil-reference
[4] http://www.ruleml.org/
[5] http://www.w3.org/TR/ws-arch/
[6] http://www.w3.org/Mobile/CCPP/
[7] http://www.u2m.org/
[8] http://dmoz.org

ing/recommending, guiding, assisting/helping [Torre, 2001], and so on for all the ontologies. At the following levels there are specialized concepts. For example, in the *tourist domain*, the next levels can include tourist categories (e.g. lodging, places), while in the *adaptation-goals ontology* they can include more specific ones such as explaining to support learning or to clarify, to teach new concepts or to correct mistakes.
Thanks to this modular structure, the framework can be used by different applications, which can select a sub-part of the most generic ontology, in the considered planes, and instantiate only the concepts they are interested in.

The basic idea of the model is that user modeling and adaptation rules can be defined on the points of combination of planes. In detail, using the model can be important since it allows to explain which classes of the ontologies are involved in the reasoning process. Given for example the adaptation-goals ontology, and in particular the goal and the sub-goals "*explaining* → *explaining to support learning* → *teaching new concepts*" the idea is that the *adaptation rule* for reaching this adaptation goal (teaching new concepts) can be defined taking into account the knowledge domain, the user's current knowledge, her preferences and, possibly, her learning approach (e.g. top-down vs. bottom-up), her current cognitive load, the current device (e.g. PDA, desktop pc) and context conditions (e.g. the noise level in the room). Finally, the definition of adaptation rules requires considering the set of available adaptation methods and techniques (such as hiding text, stretch text, audio annotations, direct guidance). Since all of these features are classes represented inside ontologies in different planes, it can be perceived that the definition of the rule derives from the combination of such planes in correspondence of the involved classes. This methodology can be exploited to define all the rules addressed by the framework, clearly taking into account the appropriate planes.

3.1 User modeling rules

For user modeling rules, which allow to infer new knowledge about the user from the available one, we consider:

- on the X_1-plane, the ontology of the *user's actions* on the system (e.g. selection, bookmark, print);
- on the X_2-plane, the ontology of the possible *domain features* (e.g. business, tourist, e-learning, shopping);
- on the X_3-plane, the ontology of the *user model* (e.g. demographic features, psychographic features, cognitive features, preferences, interests);

From the combination of dimensions on these planes we can define user-modeling rules in the form of Horn clauses:

IF** ((a **is-a-instance**-of user_actions) **AND
*(b **is-a-instance**-of domain_features) **AND***
*(c **is-a-instance**-of explicit_user_features))*
***THEN** (**instantiate** inferred_user_features **to** i_1, ...*
***instantiate** inferred_user_features **to** i_k)*

whereas *user_actions* is the *X_1Plane*, *domain_feature* is the *X_2Plane, explicit_user_features* is the *X_3Plane.* The *Body* of the rule specifies classes or properties that contribute to define the value of the inferred user's feature, which constitute the *Head* of the rule.

For example:

***IF**((<current_action=bookmark> **is-a-instance-of** user actions)*
***AND** (<current_domain_feature=pub> **is-a-instance-of** domain feature)*
***AND**(<role=student, age= between18-25, gender=F> **is-a-instance-of** explicit_user_features))*
***THEN** (**instantiate** inferred_user_feature <user's propensity to spend> **to** <medium-low>)*

This rule allows a system to infer the *propensity to spend* as a match between dimensions of each plane. In particular we assume that *propensity to spend* derives from the observation of variables such as user actions, domain features (considered as objects of user's actions) and from specific user features (age, gender and role). Giving that, the specific rule above means that: if a user makes actions like bookmarking pages and the pages she has bookmarked regard places such as pubs (in the tourist/town domain) and the user is a female, 18-25 years old, and she is a student, then we can infer that her propensity to spend may be medium-low.
Notice that we do not yet manage uncertainty or probability distributions of values, but we are working on defining a ontology of these factors and referencing it in SWRL.

3.2 Coarse adaptation rules

As already explained, the above methodology can be used to define the adaptation rules as well, clearly changing the planes to take into account. Given that, the aim of this model is to identify the right adaptation techniques to achieve the different goals and sub-goals specified in the *adaptation-goals ontology*. As a consequence, for this model we just take into account two ontologies, placed on two planes:

- on the Z_1-plane, we place the ontology of the *adaptation goals* of the system; e.g. guiding (to obtain something, to discover something), explaining (to make learn, to clarify), assisting/helping (to make decision, to solve problems, to orient and move in the hypermedia), inducing/pushing, suggesting/recommending, informing, etc. [Torre, 2001];
- on the Z_2-plane we place the ontology of the *adaptation methods/techniques,* e.g. methods and techniques for adapting contents (additional explanation: conditional text and adaptive stretch-text; content variant: page variant and fragment variant, etc.), for adapting the presentation and layout (text fading, highlighting, background changing, etc.), for adapting the navigation structure (link sorting, link annotation, link removal/addition, etc.)[9];

The definition of the adaptation rules derives from the combination of such planes:

IF** ((a **is-a-instance-of** adaptation goals) **AND

[9] Note that we defined the taxonomy of adaptation methods and techniques starting from [Kobsa etal., 2001]and [Brusilovsky , 1996]classifications and we represented the latters as sub-classes of the formers.

(b ***is-a-instance-of*** *adaptation methods/techniques))*
THEN (instantiate *adaptation techniques* ***to*** *b_1, ...,*
instantiate *adaptation techniques* ***to*** *b_k)*

whereas the *Body* specifies the adaptation goal/s that an adaptive system may want to achieve and all the possible methods and techniques, while the *Head* selects the subset of adaptation techniques which fit such goals.
In order to clarify the meaning of goal and technique, we explicitly express their isa relations, in the form of "class →subclass":

IF(*(<assisting/helping→ to move within the hyperme-dia>* ***is-a-instance-of*** *adaptation goal)*
AND *(<content→additional explanation→conditional text, adaptive stretch-text is-a-instance-of adaptation methods/techniques >),*
AND *(<navigation→direct guidance, link removal, link annotation, link sorting, adaptive maps> is-a-instance-of adaptation methods/techniques),*
AND *(<presentation→ text → enhancement, high-light ing, fading>* ***is-a-instance-of*** *adaptation meth ods/techniques))*
THEN (instantiate *candidate adaptation techniques* ***to*** *<direct guidance, link annotation, adaptive maps>)*

The meaning of this rule is that, if the adaptation goal is helping the user to move within a hypermedia, the most suitable adaptation techniques, among all of the possible ones, are using direct guidance, link annotation and adaptive maps. As said, the example includes the representation of isa relations. Therefore, for instance, the techniques *conditional text and adaptive stretch-text* are *sub-classes* of the method *additional explanation*, which is a sub-class of methods regarding *content* adaptation.
While *user modeling rules* and *detailed adaptation rules* can be exploited by specific applications to dynamically perform inferences and producing adaptation, this kind of rules can just be exploited in the design phase to restrict the number of methods and techniques for defining the *detailed adaptation rules*.

3.3 Detailed adaptation rules

This model aims at selecting the right adaptation technique, given specific user, device, domain and context features. The model is composed of the following ontologies:

- on the Y_1-plane we place the ontology of the *adaptation methods/techniques* containing the adaptation techniques (possibly selected by *coarse adaptation rules*);
- on the Y_2-plane, we have the ontology of *context conditions: usage environment* (e.g. place, motion), *physical environment* (e.g. temperature, weather), *social environment* (e.g. close people, current interactions), *time* (e.g. day, hour);
- on the Y_3-plane, the ontology of the *user model* (anagraphic, psicographic, cognitive characteristics and level of interest in domain topics) integrated/updated with the user's dimensions inferred by the previous *user modeling rules*;
- on the Y_4-plane we place the ontology of *devices* that can be used by the user (hardware component, software platform, network characteristics, browser characteristics, mobile characteristics);
- on the Y_5-plane we place the ontology which describes the possible *domain feature* (business, tourist, e-learning, shopping, and so on).

The detailed adaptation rules derive from the combination of such planes:

IF *(a_1, a_2* ***is-a-instance-of*** *adaptation method/techniques)*
AND *(b_1, b_2* ***is-a-instance-of*** *context condition)*
AND *(c_1, c_2* ***is-a-instance-of*** *user_features)*
AND *(d_1,d_2* ***is-a-instance-of*** *device)*
AND *(e_1,e_2* ***is-a-instance-of*** *domain))*
THEN (instantiate *adaptation techniques* ***to*** *a_1)*

in which the *Body* of the rule specifies the conditions to be satisfied and the *Head* of the rule specifies the adaptation technique to be used for the specific user, given user's context, device, domain.

For example:

IF *((<candidate_techniques=direct guidance, link annotation, adaptive maps>* ***is-a-instance-of*** *adaptation method/technique)*
AND *(<current_context=night, movement>* ***is-a-instance-of*** *context condition)*
AND *(<age MoreThan 65>* ***is-a-instance-of*** *user_features)*
AND*(<current_device=PDA>* ***is-a-instance-of*** *device)*
AND*(<current_domain=any>* ***is-a-instance-of*** *domain))*
THEN (instantiate *adaptation technique <in-ferred_technique>* ***to <*** *direct guidance>)*

Considering the adaptation goal to achieve (*assisting/helping→ to move within the hypermedia*) and the corresponding suitable adaptation techniques (*direct guidance, link annotation and adaptive maps*) selected by a coarse rule applied before the detailed one, we want to define the best technique for personalizing the system respect to a specific user with a specific device in a specific context and domain. The system, in order to help an elderly user with a PDA in a nightly and mobile context to orientate and move within the application provides a direct guidance through the pages of the hypermedia.

4 Exploitation of the framework

The exploitation of the framework is twofold. On the one hand, it can support designers in the development of adaptive applications (to select the most appropriate user modeling and adaptation techniques). On the other hand, it can be seen as an approach to share user modeling and adaptation knowledge.

As regards the first aspect, the framework can offer a **methodological approach** for the design of adaptive hypermedia systems based on semantic representation of knowledge. In this case the framework basic concepts are exploited by a designer of adaptive system to select the most appropriate dimensions and both user modeling and adaptation rules. In particular, the framework allows to represent ontologies on planes and the relationships among classes in a multidimensional space to generate inferences and define adaptation rules. For example, considering an adaptive application that is aimed to select the best wine with respect to the dinner menu, the specific user taste, her budget and context of eating (special occasion, lunch break), the designer can exploit the structure of the framework by:

- placing the ontologies required by the application on the planes of the framework (e.g., user model, wines, context of eating, menu);
- selecting the classes involved in the inference process in order to activate the rules (e.g., user taste and budget from the user model ontology, a specific context of eating, a particular menu)
- instantiating the rule to produce adaptation (e.g., given a user with preference for red wine and a low budget, in a house party with a meat-based menu, then the candidate wine will be "Barbera")

Moreover, the framework provides standard languages (OWL and SWRL) to represent the knowledge of the system in an integrated way and supplies development modules for converting OWL and SWRL to the syntax of rule engines such as CLIPS and Jess, which are very often deployed in adaptive hypermedia systems.

Moving to the second goal, the **re-use of knowledge** regards:

- the shared ontologies about adaptation goals, methods and techniques, user features
- the process that generates the inferences and the adaptation strategies
- the result of these processes.

This opportunity is due to the semantic representation of each knowledge entity and by the modular structure of the framework that permits to select subparts of the most generic ontology on the planes and instantiate only the needed classes.
In particular, this knowledge may be acquired and integrated in the knowledge base of the new application (and eventually extended or modified) or it can be referred to by URI (this possibility can be applied to the first and third kind of knowledge, above specified). Notice that this second possibility can only be achieved when the adaptive application is published on the Web. In that way the application can, for instance, extend its domain knowledge to an open corpus of resources, as described in Section 1.
The methodology proposed by the framework allows the design of adaptive applications as semantic web services[10]. Indeed, an adaptive system can be conceived as a web service that requires, as inputs, data from the user (age, instruction, interests, preferences) and offers, as outputs, personalized suggestions. The possibility to link these data to shared ontologies and to explain the reasoning mechanisms by semantic rules transforms the "adaptive" web service in an "adaptive" semantic web service.

5 An example of application of the framework

We are currently testing the proposed methodology with an application, UbiquiTo [Amendola et al., 2004], we previously developed. This application is a *multi-device* adaptive guide that offers personalized tourist information on the basis of explicit and implicit information about the user. In particular the user has to register and give some basic information about her, useful to generate a first set of inference. Then the system observes the user during the interaction, stores new knowledge about her and makes further inferences. Therefore, the instantiation of the ontologies on planes is restricted to the classes related to such features of the application.

For example, regarding the model for inferring user features, on the *domain Plane*, we consider the classes of the tourist domain (e.g., Lodging, Places, Arts). However, in Class Lodging, for instance, we do not instantiate the subclass "Castles", since UbiquiTo does not address it.
The same approach has been adopted for all the planes considered in the model. As explained in Section 2, ontologies on the planes are written in OWL, while rules, at the combination of planes, are written in SWRL. To support the development of the ontologies and the translation in OWL, we use the free tool Protégé 3.0[11].

6 Discussion and Related Work

In recent years the User Modeling and Adaptive Hypermedia communities have been approaching to Semantic Web technologies. Frasincar and Houben (2002), for example, developed a methodology for the design of intelligent web information systems in the Web. In this work, device capabilities are specified by means of CC/PP, while adaptation aspects, application domain, adaptivity conditions and update rules are expressed in RDFS. One of the most interesting aspects of their methodology is the design of the Application Model, which is concerned with the navigational aspects of the hypermedia presentation. They extended their Conceptual Model, expressed in RDFS, with navigational views, considered as slices of one ore more concepts from the Conceptual Model. Heckmann and Krueger (2003) developed an XML-based markup language, UserML, and its corresponding ontology, UbisWorld, to communicate user models in a ubiquitous computing environment. Every UserML document can be divided into MetaData, UserModel, InferenceExplanations, ContextModel and Environment Model. The main aim of this representation is that different user modeling applications could use the same framework and keep their individual user model elements.
Dolog et al. (2002) developed an adaptive learning application using Semantic Web technologies. Learning resources are described by means of shared ontologies (Dublin Core and Learning Objects Metadata) with their RDF bindings, and reasoning and adaptation are realized by using TRIPLE, a rule-based query language for the semantic web. Then, they also extended the adaptation capability of the systems to a global *external* context of semantically annotated resources, and they used TRIPLE to make ontology mapping, query relaxation, result filtering and finally to generate recommendations.

With respect to these works, the main contribution of our project is the definition of an *ontological framework* for managing *rules* and *ontologies* in an *integrated* and *semantic* way. In particular an innovative aspect is the layered approach to user model construction and another is the use of semantic web techniques to represent user

[10] http://www.daml.org/services/.

[11] http://protege.stanford.edu/

models and inferences. The combination of both the aspects represents the real value added.

In the framework we exploit the notion of shared reasoning strategies for semantic web applications based on user modeling, using the semantic formalism SWRL for the definition of reasoning capabilities and adaptation strategies integrating it with OWL, the standard language for the Semantic Web, which we exploit for the declaration of the knowledge base. Thus, by adopting our framework, the development of an adaptive system may benefit from the availability of: i) shared ontologies regarding the user model, domain model, adaptation methods, which the specific application can instantiate and extend, if necessary, ii) a *tool* for representing, in a unified way, all the knowledge the system is based on, iii) standard and integrated languages for representing knowledge, iiii) implementation support, given by the possibility to convert OWL and SWRL to the syntax of rule engines such as CLIPS and Jess.

As regards future work, we are going to apply this methodology to other adaptive applications (e.g., [Ardissono et al., 2003], [Cena and Torre, 2004]) in order to evaluate if our approach is useful in different application domains and successful with different adaptation techniques. Regarding the extension of the framework, we are developing rules to integrate XSLT transformation in our ontologies and generate different kind of interfaces directly from our model. Moreover we are working to manage uncertainty defining an ontology of uncertainty factors and referencing it in SWRL. Finally, we are working on the extension of ontologies on each plane and, as a medium-term objective, on the extension of the framework in the direction of semantic web services, as described in Section 4.

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8 References

[Amendola et al., 2004]
Amendola I., Cena F., Console L., Crevola A., Gena C., Goy A., Modeo S., Perrero M., Torre I., Toso A.: UbiquiTO: A Multi-device Adaptive Guide. In the Proceedings of Mobile HCI 2004, Lecture Notes in Computer Science, 3160 (2004) 409-414

[Antoniou and Van Harmelen, 2004]
Antoniou, G., Van Harmelen F.: A Semantic Web Primer. The MIT Press, Cambridge, MA, (2004)

[Ardissono et al., 2003]
Ardissono L, Gena C., Torasso P., Bellifemine F., Chiaretto A., Difino A., Negro A. : Generation of personalized Electronic Program Guides. LNCS n. 2829. AI*IA 2003, Springer Verlag, (2003) 474-486

[Brachman and Schmolze, 1985]
Brachman R.J., Schmolze J.: An Overview of the KL-ONE Knowledge Representation System. Cognitive Sci 9(2) (1985)

[Brusilovsky , 1996]
Brusilovsky P.L.: Methods and Techniques of Adaptive Hypermedia. *In User Modeling and User-Adapted Interaction* 6 (1996) 87–129

[Carmagnola et al., 2005]
Carmagnola, F., Cena, F., Gena, C., Torre, I. A Multidimensional Approach for the Semantic Representation of Ontologies and Rules in Adaptive Hypermedia Systems. In the *workshop proceedings of conference "UM'05, the Tenth International Conference of User Modeling"*, Jul. 24-29 2005, Edinburgh, Scotland

[Cena and Torre, 2004]
Cena, F., Torre, I.: Increasing Performances and Personalization in the Interaction with a Call Center System. *In the Proceedings of the 8th ACM International Conference on Intelligent User Interfaces*, Funchal, Madeira, Portugal, (2004), 226-228

[Dolog et al., 2004]
Dolog, P., Henze, N., Nejdl, W., Sintek, M.: The Personal Reader: Personalizing and Enriching Learning Resources using Semantic Web Technologies. *In the Proceedings of the AH 2004*, Eindhoven, The Netherlands, LNCS, Springer Verlag (2004) 85-94

[Frasincar and Houben, 2002]
Frasincar F., Houben G.: Hypermedia Presentation Adaptation on the Semantic Web. *In the Proceedings of the AH 2002, LNCS*, Springer Verlag (2002) 85-94

[Gruber, 1993]
Gruber R.: Toward Principles for the Design of Ontologies Used for Knowledge Sharing. Stanford Knowledge Systems Laboratory Technical Report KSL (1993) 93-04

[Heckmann and Krueger, 2003]
Heckmann D. and Krueger A.: A User Modeling Markup Language (UserML) for Ubiquitous Computing, in *LNCS 2702*, Springer Verlag (2003), 393 - 397

[Kay et al., 2002]
Kay, J., Kummerfeld, R., Lauder P.: Personis: A Server for User Models. *In the Proceeding of the AH, LNCS*, Springer Verlag (2002) 203-212

[Kobsa etal., 2001]
Kobsa, A., Koenemann, J., Pohl, W.: Personalized Hypermedia Presentation Techniques for Improving Online Customer Relationships. *The Knowledge Engineering Review* 16(2) (2001) 111-155

[Mizoguchi et al., 1997]
Mizoguchi R., Ikeda M., Sinitsa K.: Roles of shared ontology in AI-ED Research. In the Proceedings of AI-ED, (1997) 537-544

[Torre, 2001]
Torre I.: Goals, tasks and Application domains as the guidelines for defining a framework for User modeling. *In the Proceedings of User Modeling 2001*, *LNCS*, Springer Verlag (2001), 260-262