A Semantic Framework for Adaptive web-based Systems

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Abstract. This paper proposes a semantic framework built on multidimensional ontological matrices 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 intersection between planes allows us to represent semantic rules for inferring new user features and to define adaptation strategies. We exploit OWL to represent taxonomic knowledge and SWRL for rules. The framework presents a new approach to build adaptive web-based systems that support interoperability.

1 Introduction

Adaptive web-based 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, etc.) to the user [6]. Current adaptive systems also take into account other features, besides the user model, such as the context of interaction, the device, etc. 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* [9]. 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 [13]. 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 web-based 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 (of the user, of the context, of the 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 user models, domain knowledge, etc..., with ontologies expressed in a standard semantic markup language for the Semantic Web, OWL[1], and (ii) the inference rules with SWRL[2], an input for W3C's future semantic rules work.

The paper is organized as follows. In Section 2, we explain why we use a semantic knowledge representation. In Section 3 we present the goals of the framework, which is described in detailed in Section 4. Then, Sections 5 presents an example of application of this framework in the domain of Adaptive web-based systems (AHs). Finally, Section 6 introduces the related works and concludes the paper.

2 The choice of a semantic knowledge representation

As mentioned in the introduction, most adaptive web-based 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 have exploited ontologies, often in the form of mere taxonomies, 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, etc. [9], [12]. 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 taxonomies are concerned, we use them since they allow to represent and share conceptualizations of a certain knowledge domain [11] and contain a large set of pertinent concepts (entities, attributes) and the relations among them (IS_A, PART_OF, PORPUSE_OF, etc.).

OWL is the formalism we chose to express ontologies because:

- it is the new standard ontology language of the Semantic Web, defined by W3C;

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

[2] http://www.w3.org/Submission/SWRL/

[3] http://www.w3.org/TR/daml+oil-reference

- 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, etc.), they need rules to make further inferences and to express relations that cannot be represented by ontological reasoning (e.g., in a learning domain it could be necessary to express the fact that a topic A is a prerequisite of topic B to make the right suggestions to the user).
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 allow also 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"[2]. In this way, the proof presentation can be considered as a way for humans/machine 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, etc.

Summarizing, a semantic representation of rules has different purposes, in particular:

- it enables knowledge sharing between software agents and human designers;
- it enables to compare and evaluate rules, detect incompatibilities, validate or possibly refuse them both in the design phase and in the execution phase;
- in the field of adaptive systems, it allows to give explanations about the reasoning strategies of the system adaptive behaviour and of its adaptations.

3. Goals of the framework

The goals 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.

[4] http://www.ruleml.org/

As regards the first aspect, the framework can offer an **approach** for the design of adaptive web-based systems based on semantic representation of knowledge. In this case the framework basic concepts are exploited by a designer of adaptive web-based systems 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. Moreover, the framework aims to provide standard languages (OWL and SWRL) to represent the knowledge of the system in an integrated way.

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[5]. 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.

A linked possibility of exploitation deals with the idea of allowing software agents to dynamically access the framework to obtain inferences and adaptation rules. In this scenario, the framework could be seen as a sort of semantic web service which provides knowledge to agents which finally provide adaptive services to end users. To achieve this goal, all the applications developed by means of the framework have to be linked into the framework, which could become a dynamic user model server that shares both the process that generates the inferences on user model dimensions and the result of these processes. This user model server can be conceived as a semantic web service, since the ontologies on the planes, the inference processes and the results of the inferences are semantically described.

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

4 Description of the framework

The framework we propose aims at supporting the visual design (see Figure 1), the semantic representation of knowledge bases and rules, and their implementation in adaptive web-based 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 Internet and the Web*": it is used by almost all web 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 and the possibility to link such taxonomies and integrating them with semantic web technologies and Web Services[6].

For the definition of this semantic framework we developed a multidimensional matrix composed of different planes. 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's 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 web-based systems:

- *user modeling rules* that add knowledge about a user by inferring new user features from other features,
- *adaptation rules* that can be divided into two different types:
    - *coarse adaptation rules*, that define the strategies of adaptation, given the adaptation goals,
    - *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 application independent 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 separa-

[6] http://www.w3.org/TR/ws-arch/

tion, as seen above, in different ontologies for the model of the user, of the device, of the domain, etc.

In some planes we exploit and extend shared ontologies (in particular CC/PP[7] for the device, Ubisword[8] for the user and the context features, the Open Directoy Project for the domain[9]), since they can be 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, considering the *domain ontology*, the first level includes macro domain definition such as: tourist domain, financial domain, e-learning domain, etc.; considering the *adaptation-goals ontology*, the first level specifies general goals such as: inducing/pushing; informing, explaining, suggesting/recommending, guiding, assisting/helping [16], and so on for all the ontologies. At the following levels there are specialized concepts. For example, in the *tourist domain*, the second levels can include tourist categories (lodging, places, etc.), while in the *adaptation-goals ontology* they can include more specific concepts such as explaining to support learning or to clarify, to teach new concepts or to correct mistakes, etc.
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 matrix is that user modeling and adaptation rules can be defined on the points of intersection between planes. In detail, using the matrix 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 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, etc.). 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 intersection 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.

User modeling rules

[7] http://www.w3.org/Mobile/CCPP/
[8] http://www.u2m.org/
[9] http://dmoz.org

For this kind of, 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 (selection, bookmark, print, etc...);
- on the X_2-plane, the ontology of the possible *domain features*[10] (business, tourist, e-learning, shopping, etc...);
- on the X_3-plane, the ontology of the *user model (*demographic features, psychographic features, cognitive features, preferences, interests, etc.);

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

If *((X_1Plane user actions=a_1, $a_{2,\ldots}$ a_n)*
AND *(X_2Plane domain_feature= b_1, $b_{2,\ldots}b_n$)*
AND(*X_3Plane explicit_user_features= $c_1,c_{2,\ldots},c_n$))*
Then *(inferred_user_features= $i_1,i_{2,\ldots},i_n$)*

in which the *Body* of the rule specifies classes or properties of classes that contribute to define the value of the inferred user's feature, which constitute the *Head* of the rule.
For example:

If *((X_1Plane user actions <current_action=bookmark>)*
AND *(X_2Plane domain feature <current_domain_feature=pub>)*
AND(*X_3Plane explicit_user_features <role=student, age= between18-25, gen der=F>))*
Then *(inferred_user_feature <user's propensity to spend=medium-low>)*

The matrix representation for this rule is shown in **Fig. 1**.

This rule allows a system to infer the user's feature *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 (taken into account as objects of users 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 popular 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, at this moment, we do not manage uncertainty or probability distributions of values, but we are working on defining a taxonomy of uncertainty factors and referencing it in SWRL.

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[10] Notice that the level of interest in domain topics is represented as an *overlay model* [6]. The idea of the overlay model is to represent an individual user's interest in a subject as an "overlay" of the domain model. For each domain model class and subclass, an individual overlay model stores some value which is an estimation of the user interest level towards these classes and subclasses. For instances, given the subclass *pub* the level of interest of the user can be represented as *pub* <user_interest=high>, and so on for all the classes-subclasses of the domain for which a possible value has been inferred.

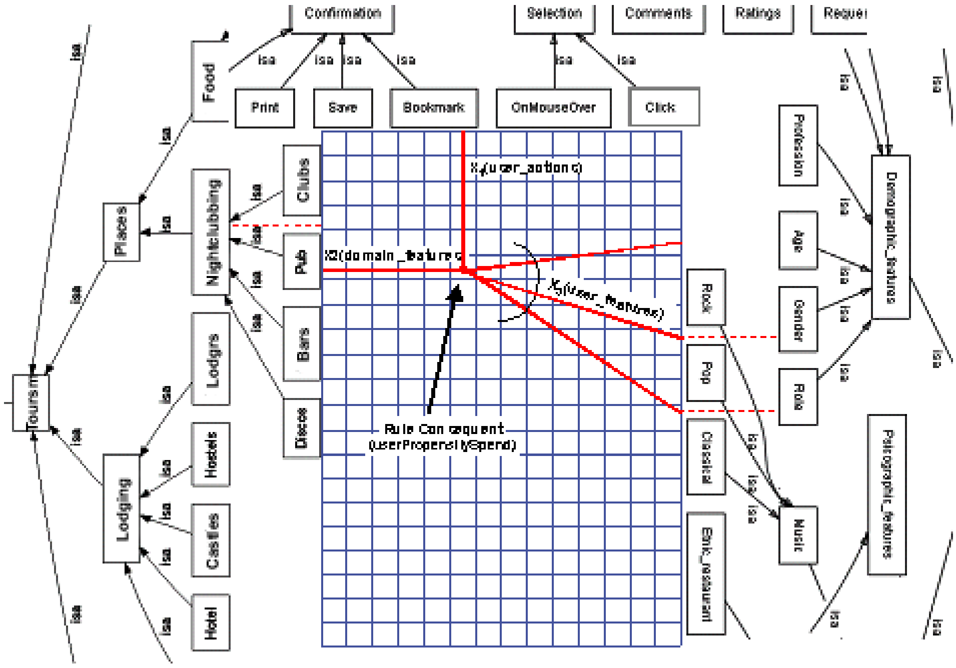

Fig. 1. A matrix for inferring user propensity to spend

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 matrix is to identify the right adaptation techniques to achieve the different goals and sub-goals specified in the Goals taxonomy. As a consequence, for this matrix 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, etc...), explaining (to make learn, to clarify, etc...), assisting/helping (to make decision, to solve problems, to orient and move in the hypermedia, etc.), inducing/pushing, suggesting/recommending, informing, etc...[16];
- 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.)[11];

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

If *((*Z_1*Plane adaptation goals =* $a_1, a_{2,\dots} a_n$*)*
  AND *(*Z_2*Plane adaptation methods/techniques =* $b_1, b_{2,\dots}\ b_n$*))*
Then *(adaptation techniques=* $b_1, b_{2,\dots,} b_n$*)*

in which the *Body* of the rule specifies the adaptation goal/s that an adaptive system may want to achieve and all the possible methods and techniques, while the *Head* of the rule selects the subset of adaptation techniques which fit such goals.

Below, we present an example. In order to clarify the meaning of goal and technique names, we explicitly express their super-classes, in the form of class_1→subclass_{11} →subclass_{111}:

If *((Z* $_1$*Plane adaptation goal <assisting/helping → to move within the hypermedia>)*
  AND *(Z* $_2$*Plane adaptation methods/techniques*
    <content→additional explanation→conditional text, adaptive stretch-text, etc.>,
    <navigation→direct guidance, link removal, link annotation, link sorting, adaptive maps, etc.>,
    <presentation→text→enhancement, highlighting, fading, etc..>))
Then *(candidate adaptation techniques <direct guidance, link annotation and 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 class-subclass relations. Therefore, for instance, the techniques *conditional text and adaptive stretch-text* are *subclasses* 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 to take into account in the matrix for defining the detailed adaptation rules.

Detailed adaptation rules

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

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[11] Note that we defined the taxonomy of adaptation methods and techniques starting from Kobsa et. al. [14] and Brusilovsky [6] classifications and we represented the latters as subclasses of the formers.

- on the Z_1-plane we place the ontology of the *adaptation methods/techniques* containing the adaptation techniques (possibly selected by coarse adaptation rules);
- on the Z_2-plane, we have the ontology of *context conditions: usage environment* (place, motion, etc.), *physical environment* (temperature, weather, etc.), *social environment* (close people, current interactions, etc.), *time* (day, hour, etc.);
- on the Z_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 Z_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 Z_5-plane we place the ontology which describes the possible *domain feature* (business, tourist, e-learning, shopping, etc.).

The activation rules derive from the intersection of such planes:

If *((Z_1Plane adaptation method/techniques = b_1, b_2)*
  AND *(Z_2Plane context condition = c_1, c_2,… ,cn3)*
  AND *(Z_3Plane user_features = d_1, d_2,…, d_n)*
  AND *(Z_4Plane device = e_1, e,…,e_n)*
  AND *(Z $_5$Plane domain = f_1, f_2,…,f_n))*
Then *(adaptation technique= b_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 *((Z $_1$Plane adaptation method/technique <candidate_techniques=direct guidance, link annotation and adaptive maps>)*
  AND *(Z $_2$Plane context condition<current_context=night, movement>)*
  AND *(Z $_3$Plane user_features<age= >65>)*
  AND*(Z $_4$Plane device<current_device=PDA>)*
  AND*(Z $_5$Plane domain* <current_domain=any>*))*
Then *(adaptation technique <inferred_technique=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 can only provide a direct guidance through the pages of the hypermedia.

5 An example of application of the framework

We are currently testing the proposed methodology with an application, UbiquiTo [1], 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 provide 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 matrix for inferring user interests, we consider the classes of the tourist domain (e.g., Lodging, Places, Arts, etc.). 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 matrix. As said in Section 3, some ontology is based on and extend public and shared ontologies (CC/PP for the device, Ubisword for the user and the context features, Open Directoy Project for the domain).

As explained in Section 2, ontologies on the planes are written in OWL, while rules, at the intersection 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[12]. As it is a standard language we do not provide an example here.

In the following we show an example of SWRL code for representing the above defined rule (see Fig.1), which derives user's "*propensity_to_spend*" starting from other user's features and user's actions on a specific domain. The the full code can be found in [7].

In detail, we considered a female user that made a login into the system, filled in the registration form to look for some information. From this source the systems knows that she is 25-years old, she is a student and she made the action of bookmarking a page regarding nightclubbing (in the specific case a pub).

Given these values regarding user's age, role, gender and action on a specific domain feature, the rule infers that user's "*propensity_to_spend*" is "*medium low*". After defining the ontologies involved in the rule (user, actions, domain), we specify properties and instances of all the classes implied in the inference. For example, for the property "*age*" we have:

```
<swrlx: datavaluePropertyAtom swrlx:property="age">
   <ruleml:var>user</ruleml:var>
   <owlx:DataValue owlx:datatype="&xsd;integer">25</owlx:DataValue>
</swrlx:datavaluedPropertyAtom>
```

Then, we define new user's features (for example propensity to spend) that emerge at the point of intersection between planes:

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

```
  <swrl:propertyPredicate rdf:resource="&URI;propensityToSpent"/>
 <ruleml:var>user</ruleml:var>
  <owlx:Individual owlx:name="medium-low"/>

  </swrlx:individualPropertyAtom>
   <swrl:argument1 rdf:resource="#user"/>
   <swrl:argument2 rdf:resource="#actions"/>
   <swrl:argument3 rdf:resource="#domain"/>
   </swrl:individualPropertyAtom>
```

Note that each component of the framework is ontologically represented as a class. Thus we have for example the User Model Class, the Context Model Class, the Device Model Class, etc. In this way, a specific user model represents an instance of the User Model Class, a specific context model represents an instance of the Context Model Class, etc. Moreover, each Class (representing the User Model, the Context Model, etc.) is characterized by a set of properties, that are the user features, the context features, and so on. The properties are mapped on the classes in the corresponding ontology. For example, the *User Model* property "Age" is mapped on the Class Age of the *User Model Taxonomy* and the allowed values for this property are the instances of the Classes in the corresponding taxonomy (in OWL the instance of the class Age is the range of the property Age).

Therefore, inferences and adaptation rules are written taking into account the properties of the models, which are mapped on the taxonomies.

6 Conclusion and Related Work

In recent years the User Modeling and Adaptive web-based community has been approaching to Semantic Web technologies.

Frasincar and Houben, for example, developed a methodology for the design of intelligent web information systems in the Web [10]. 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 [12] 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. [9] 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 *taxonomies* in an *integrated*, *semantic* and *visual* 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 models and inferences. The combination of both the aspects represents the real value added.

In this framework we exploit the notion of share reasoning strategies for semantic web applications based on user modeling, using the SWRL for the definition of reasoning capabilities and adaptation strategies with OWL, 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, etc. which the specific application can instantiate and extend, if necessary, ii) the *matrix* 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., [3], [8]) 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 resource and generate different kind of interfaces directly from our model. Moreover we are working to manage uncertainty defining a taxonomy of uncertainty factors and referencing it in SWRL. Finally, we are working on the extension of taxonomies on each plane and, as a medium-term objective, on the extension of the framework in the direction of web service, as described in section 4.

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