Journal of Universal Computer Science, vol. 16, no. 12 (2010), 1539-1555
submitted: 29/12/09, accepted: 5/5/10, appeared: 28/6/10 © J.UCS

A Context Model based on Ontological Languages: a Proposal for Information Visualization

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Abstract: In the last few years, people are increasingly demanding personalized information to carry out their daily activities. Information systems are needed to manage a representation of the user's situation, identify user needs and preferences, and implement information retrieval techniques that pull together data from diverse and heterogeneous sources. It is necessary to define and formalize context models for achieving these goals. In this paper, we present a formal context model based on advances on the Semantic Web. The model is compounded by four independent and related ontologies: users, devices, environment and services. Each of these ontologies describes general concepts and relationships involved in intelligent environments. The proposed design enables model specializations to particular domains and interoperability with external ontologies. Moreover, the model supports inference mechanisms to enhance the automatic context generation and the proactive behavior of particular services. Finally, this paper shows a specific prototype that offers personalized and context-aware information to the user, aided by the context model.

Keywords: Context-awareness, Knowledge Management, Semantic Web, Information Visualization, Ambient Intelligence
Categories: I.2.4, H.5.2, M.4

1 Introduction

Context-awareness is recognized as a fundamental enabler for adaptivity and proactivity in a wide variety of computational services. In general, we could have an approximate and common vision of what the context means. However, it is a broad and ambiguous concept and it must be defined. Anind K. Dey states: "Context is any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves". With regards to this idea, Dey defines Context-Aware application as "A system that uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task" [Dey, 2001].

Due to the vague and wide definition of context, we need models to characterize parts of the reality, or more precisely, to represent the context as an information source. In an initial analysis, there are five main aspects to consider, called the five W's theory: Who, Where, When, What and Why [Brooks, 2003], a theory applied to many fields, journalism and psychology among others. This classification is not enough to model the context appropriately; a more detailed taxonomy is expected. [Section 4] includes our proposal of taxonomy for modeling the context.

In this paper we propose an approach based on the Semantic Web that combines model-driven approaches and rule-based systems, increasing the expressiveness of the model, enabling knowledge management techniques and reasoning mechanisms. This method can enhance the degree of independence between context and business logic of the services, reduce the adaptation effort and increase the system flexibility.

This paper is structured as follows. [Section 2] is dedicated to analyze the context model backgrounds. [Section 3] introduces the context modeling by means of ontological approaches. [Section 4] presents our Semantic-powered context model and a particular prototype, and finally, [Section 5] concludes this paper.

2 Context Model Backgrounds

In recent years, a wide trend in context modeling research is visible, involving several issues. For example, context detection, the ability to capture context information and show it to the users directly or embedded into services; explicit representation, previous knowledge about the environment and its components through a model description; context adaptation, the ability to implement or modify services by automatic context changes; context resources discovery, the ability to discover and use resources related to the current context; context queries, methods of accessing specific sets of information; and context scalability, obtaining new information from the context through existing information.

There are a variety of proposals to the mentioned issues. Model-driven approaches enable the handling of context by definition of domain-specific modeling languages. For example, UML has been widely used to this objective [Grassi and Sindico, 2007; Sheng and Benatallah, 2005; Desmet et al., 2007]. Rule-based reasoning approaches are another option that usually combines knowledge management systems with a number of rules and activation conditions to generate and manage context [D'Hondt and Jonckers, 2004; Daniele et al. 2007]. Focusing on the developed of context infrastructures, there are also multiple proposals, for example, the Context Toolkit [Dey and Abowd, 2000], a set of widgets and a distributed infrastructure that hosts software components providing applications with access to context information while hiding the details of context sensing; the DOG Project [Roman, 2003], a framework that binds applications to users, uses multiple devices simultaneously, and exploits resource management within the users' environment that reacts to context and mobility; and the SoaM Architecture [Vazquez et al., 2006], a Web-based environment reactivity model that uses orchestration mechanisms to coordinate existing smart objects in pervasive scenarios to achieve automatic adaptation to user preferences. Recently, Semantic Web languages have been used for this purpose, for example the CONON model [Gu et al., 2004], focused on representing, manipulating and accessing context information; COBRA Architecture

[Chen et al., 2003], an agent-based infrastructure that includes a context broker in order to maintain a shared context model; and the Hatala proposals [2005], which include a rule-based system to define the behavior of an augmented audio reality system.

We can identify initial requirements to model the context, adapted and extended from [Strang and Linnhoff-Popien, 2004; Fuchs et al., 2005]:

- Generality: The quality of having widespread applicability, at least, at the studied domain. Mechanisms to adapt the model to related domains are desirable.
- Richness and detail: Usually the generality and the detail level are contradictory requirements. It is very important to attain an agreement between these issues.
- Distributed composition: Most ubiquitous systems originate from distributed systems and the context model should support this characteristic.
- Partial Validation: Context information and contextual interrelationships are complex and usually are error-prone. Development of validation mechanisms is particular desirable.
- Quality of information: Models should represent quality and richness annotations.
- Ambiguity handling: Context information is usually incomplete and/or ambiguous. The model must identify and quantify this characteristic.
- Level of formality: the formalization enables the computation of the contextual knowledge.
- Applicability to real environments: It is a particular challenge to use the context model in real environments and make it interoperable to existing systems.
- Evolutionary development: The context model should support adaptability and evolutionary design. Moreover, additional services and requirements should be integrated in the model at run-time.
- Interoperability: The existing models can be reuse or adapted, thus it is important keep in mind the needed mechanisms to interoperate models.
- Reasoning and inference: Most of context information is not directly acquired; the gathered information (low-level context) may be processed to obtain high-level context information by composition, abstraction or inference techniques.
- Ease of use: Usually, people who are not the initial designers carry out the final design and the maintenance of context-aware systems. The adaptation to specific domains should be easy and concise.

3 Modeling by means of ontological formal definition

Ontology is a specification of a conceptualization, that is, a formal description of the relevant concepts and relationships in an area of interest, simplifying and abstracting the view of the world for some purpose [Gruber, 1993]. Originally, ontologies have been applied in Artificial Intelligence, but recent researches have evidenced their usefulness in context modeling [Dogac et al., 2003].

An Ontology can be specified through several formal mechanisms. In a simple view, we can represent ontological concepts using basic modeling languages such as entity-relationship model. Otherwise, frame-based languages allow the definition of concepts and relationships. Expressive alternatives are logic-based models, for example First-order Logic, which allow the specification of concepts, relationships and restrictions. The challenge is the agreement between expressiveness and computability.

The use of ontologies in Ambient Intelligence brings forward several benefits and additional functionalities. However, the usual application of ontologies is in the human knowledge sharing, without a formal computational representation and management. Ontologies formalization is the first step for exploiting the benefits of this kind of formal conceptualization.

Analyzing and extending several surveys [Chen et al., 2003; Gruninger and Lee, 2002; Wang et al., 2004] we can identify significant benefits and functionalities of ontology-powered modeling:

- The ontology development expressed in formal languages provides a means for explicit knowledge representation. In general, ontologies are a powerful mechanism for structuring, organizing and reusing knowledge.
- Ontologies have the expressive power for acquiring context from diverse and heterogeneous sources (for example, sensed context, repositories and user inputs)
- It is possible to apply reasoning and inference mechanisms by means of explicit representation of semantics, reducing inconsistencies and generating additional context.
- Ontologies enable the interoperability among models or specific domain vocabularies. Besides, heterogeneous systems can define the semantics of shared concepts, and in this way, work together.
- Pervasive environments comprise technologies and services, ontologies may reduce the difficulties related to the technological diversity, reducing the adaptation effort and increasing the element reuse.
- Ontologies allow and simplify the communication among humans, computational systems, and also, between humans and systems.
- Ontologies enable the selectively access subsets of large amount of maintained context. Mechanisms to represent the expressivity of the queries about context elements, including queries made by humans as well as agents and systems, are also important.
- Proactivity in context-aware system is improved by ontologies. It is possible to define smart behaviors of the environment entities depending on the context situation.
- Ontology-powered models may reduce the cost of implementing and maintaining the context model, for example, reducing needs of redundant sensors or automating the deleting of obsolete or erroneous sensor measures and context individuals.
- Ontologies may enable the detection of inconsistencies and, even, resolve them through historical information or combining another valid context data.
- Ontologies facilitate the dynamic and spontaneous entities discovery.

Focusing on the balance between expressiveness and computability, Semantic Web languages provide mechanisms to achieve this objective and consequently enable a formal knowledge representation that enhance the capabilities of model computational processing, its adaptability, and even promote their massive use.

In general, the adaptation of Semantic Web principles to pervasive environments offers important benefits. The representation of context, in particular by means of Semantic Web languages can provide a richness and unambiguous definition of relevant concepts in the environment domain. The architecture of the Semantic Web is built upon a set of languages and technologies. The syntax is provided by XML. The mechanism to represent information about resources is known as Resource Description Framework (RDF) and the taxonomical organization is enabled using the RDF Schema. Web Ontology Language (OWL) extends RDFS by including more expressive constructors to describe the semantics of the elements. Finally, SPARQL is a query language to retrieve information from web data sources. [Section 4] focuses on the proposed model defined by OWL.

4 Our proposal: A generic and adaptable context model

Context is a broad, inaccurate and non-delimited concept. Several definitions have been proposed to Context in the Computation Area. Moreover, the main elements of the context are neither well defined nor delimited. Dey and Mankoff [2005], focusing on the context acquired through sensors, identify four categories of context information: identity, location, activity and time. Gross and Specht [2001] define the 4 dimensions of the context, another proposed classification: location, identity, time and environment. Thevenin and Coutaz [1999], on their side, set three main elements: user, platform and environment.

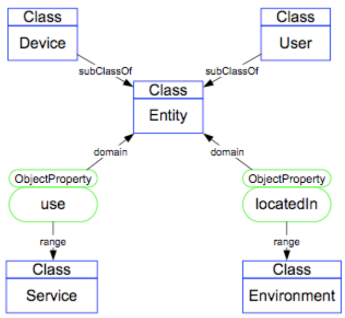

Figure 1: Upper-level context level

We propose a user-centered classification compounded by the own user, environment, devices and services, as shown Figure 1. It seeks a more general classification. Location, identity, activity and time are properties of our main elements, in an upper-abstraction level (called meta-context). Platform, system and application are concepts embedded on the service element but defined from the user view. The smart environment offers services to the users through devices and using one or several applications, platforms and systems, transparently.

As we introduce previously, context can be analyzed from the perspective of the 5 Ws Theory, a journalism principle that is regarded as basics in information gathering. Brooks [2003] proposed the adaptation of the 5 Ws theory in the design of context-aware systems. Following this proposal, we present a two-dimensional taxonomy of context elements. The first dimension is compounded by the four main categories of context: user, environment, device and service. The second one is based on the 5 Ws theory. Table 1 describes the proposed taxonomy.

Categories	**What (W1)**	**Who (W2)**	**Where(W3)**	**When (W4)**	**Why (W5)**
Users (U)	What user and what he is doing	Detailed profile and social relationships	Where the users are and perform their tasks	When the user perform tasks	Why the user is doing something at this place
Environment (E)	What environment and what objects are.	What kind of users are in the environment	Where the objects are placed	When the objects are available	Why the environment is organized in this way
Service (S)	What services are offered	Who uses these services	Where the services are offered and used	When the services are offered and used	Why these service are offered and used
Devices (D)	What devices are available	Who use the devices	Where devices are placed	When devices are available and used	Why the devices are included

Table 1: Two-Dimensional Context Taxonomy

4.1 User Model

Traditionally, user modeling has been defined together with application design, making difficult to distinguish between user and application concepts. General endeavor has been improving user models instead of reusability and generalization. However, some proposals have contributed on the formalization of user models. For example, Finin [1989] designed GUMS, a general architecture of a domain independent system for building and maintaining term models of individual users. GUMS architecture enables the development of more-complex systems, for example UMT [Brajnik and Tasso, 1994], which includes mechanisms for inconsistency resolution, PROTUM [Vergara, 1994], including complex stereotypes or Toolkit UM [Kay, 1995]. More recently, efforts to make user models general and interoperable continue. For example, Gumo [Heckmann at el., 2005] is a generic OWL ontology for uniform interpretation of user models.The problem appears when these systems work with diverse and heterogeneous applications because they are not designed as a model server [Kobsa, 2001], appearing problems of redundancy, concurrent access, security and consistency.

User modeling in Ambient Intelligence must support additional requisites concerning it broadness and dynamism:

- Ambiguity solving: usually, few user model data is acquired from environment sensors or devices and may be untrustworthy.
- Privacy and feedback (Scrutability): context-aware systems update user information depending on the user's situation. It is important to enable mechanisms to the user to supervise and modify personal information.
- Model formalization: most of user models have been conceived to improve the design phase of applications and are focused on expressive graphical representations. This kind of user model is unsuitable to be computable.
- Model generalization: user model should support diverse usage purposes. This fact brings us reutilization and adaptation mechanisms.
- Personal information embodying: pervasive environments usually associate personal information of the user through personal devices (for example, into the mobile phone and RFID tags). This information must be acquired and be incorporated in the user model as valid instances.
- Launching: in Ambient Intelligence, system startup is a critical issue. Pervasive environments are, by nature, highly dynamic and user model must support the spontaneous incorporation of new users, at run-time.

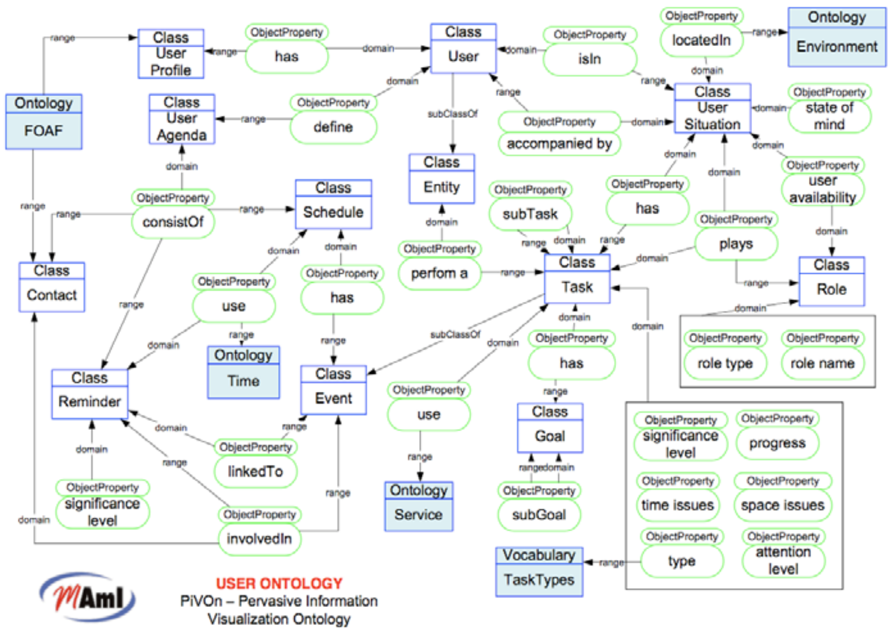

Figure 2: The User Model Ontology: a simplified view.

Figure 2 shows a summary of the user ontology. The user model has been designed for asking three basic questions: What are the user characteristics? What the user want to do? and What is the user doing?. The answers to these questions belong to the three main parts of the user model. First, the static characteristics of users have been described in the User Profile. It includes personal data, interests, affiliations, etc. All this information is not invariable but it either changes frequently. The second part includes the activity planning and it is called User Agenda. The activity granularity is not imposed; fleeting actions as well as long-time activities can be instanced. Finally, the user's situation is modeled including the dynamic and circumstantial issues of the user, for example the accompanists, the user location, and the current task and goals.

4.2 Device Model

Typically, intelligent environments include software and hardware elements that enable specific functionalities and general services altogether. The environment must support spontaneous inclusion of new devices, acquiring their characteristics and upgrading the global device information. In order to achieve this requirement, a common framework between the general context model and the devices is necessary, i.e. an expressive language to enable the communication, dynamically and automatically.

Advances in ontological languages improve the description of device characteristics, associating semantics and enabling mechanisms for sharing profiles. Concretely, formal ontological languages like OWL allow the hierarchical and independent conceptualization to enable reuse and sharing of device information.

There are few ontological proposals in device modeling but, usually, they are focused on specific kind of devices. For example, UAProf [1]specification is concerned with capturing information for wireless devices or FIPA Device Ontology[2] that intends to be general but offers low-expressiveness in peripheral device descriptions. There are also some examples of generic device models [Bandara et al., 2004; Chakraborty et al., 2001; Lopez de Ipiña et al., 2006; Garcia-Herranz et al., 2008] that include mechanisms for gathering device descriptions. However, these device models include information about location and services, making difficult the model reuse or adaptation in different domains.

Our device model proposal is shown in Figure 3 and describes the follow issues:

- Definition of relationships between the device model and the service and user ontologies, keeping the independency to maximize the knowledge sharing with external systems.
- Conceptualization of device status, defining general properties (for example the device availability and its location based on the environment model) and enabling the specialization of the status depending on the device peculiarities.
- Dependencies and relationships between devices, for example, the compatibility level, devices that delegate to others, and linking associations.
- Taxonomical organization: our proposal difference four types of devices: sensors, actuators, autonomous devices and dependent devices.
- Software and hardware profiles. We define the general characteristics explicitly and, once again, including mechanisms based on OWL to enable the model specialization.

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[1] http://www.mobilemultimedia.be/en/uaprof/
[2] http://www.fipa.org/specs/fipa00086/XC00086C.html

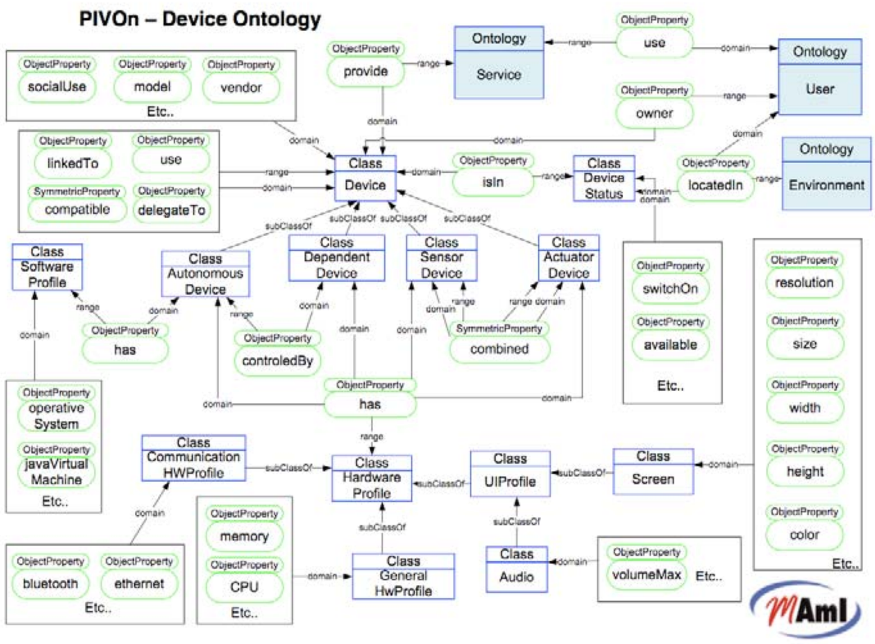

Figure 3: The Device Model Ontology: a simplified view.

4.3 Environment Model

Environment is a physical space organized in a specific way that includes inanimate objects and users. Scientific bibliography gathers several environment models although usually they are excessively linked with specific domains. For example, the environment model of the Intellibadge project [Cox et al., 2003] and the Bravo [2006] proposals are focused on conference spaces. There are environment model proposals designed through ontological languages that attempt to be widespread applied. The CONON [Wang et al., 2004] project and COBRA [Chen et al., 2004] architecture offers an interesting vision of environment models using formal knowledge representation based on ontologies. However, the limited taxonomical organization and the borderline ambiguity between environment model and the user, device and services ontologies, made us to define another formal model.

Our environment ontology is related to the rest of context model through the *Entity* class, the mother class of the *User* and *Device* entities. The ontology has been designed upon a taxonomical organization of spaces and following a premise of generality to be applied in multiple domains. Consequently, the detail level is low and it is necessary to adapt the model to the peculiarities of each environment.

Moreover, pervasive environments may support context-awareness systems that endow inanimate objects with computational significance. Consequently, it is very important to describe objects in the context-model, by associating information to them. Our model, besides modeling the objects, describes their physical organization. A simplified graphical representation is shown in Figure 4.

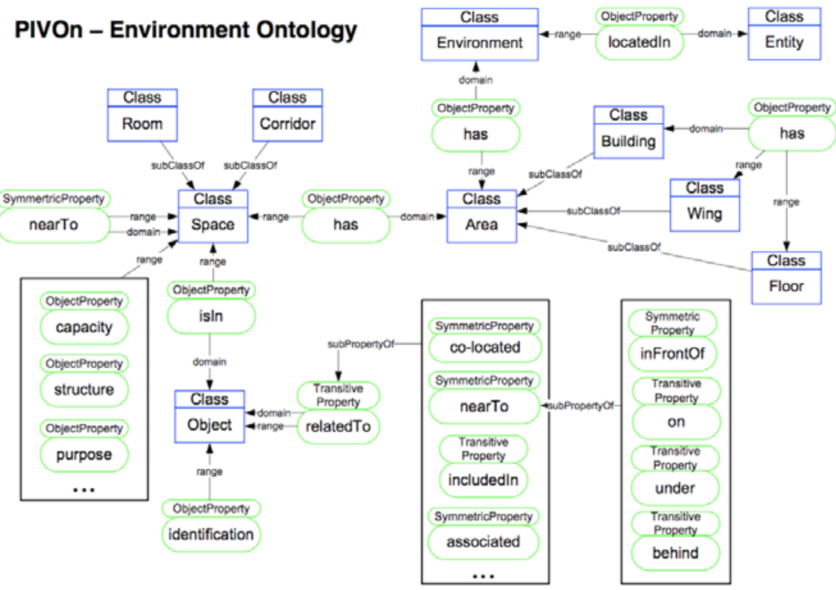

Figure 4: Environment Model Ontology: a simplified view.

4.4 Service Model

As we said previously, our context model has been designed from a generic perspective, including general aspects involved in smart environments and following a user-centered perspective. The set of available services is huge, and it is necessary to define an ontological model for each kind of service. The model infrastructure enables the taxonomical organization and mechanisms to integrate a specific service models to the above-described context-model. [Section 4.4.1] describes the concepts used for the information visualization services that offer adaptive content to the users depending on their profiles and contextual situation. Moreover, the design effort required to apply the context-awareness infrastructure to this particular service has been analyzed and illustrated through a specific prototype.

4.4.1 Visualization Services

Information visualization is a multi-disciplinary area, so it is hard to construct an ontological representation for it. For this reason, we have identified several important concepts, classifying them according to the criteria for constructing a taxonomy [Hervas et al. 2008] that guides the process of building the correspondent ontology. As a result, we have organized the ontology elements as follows:

- Relationship between visualization and relevant elements of the context: visualization process should not be limited to the visual data representation, but should rather be understood as a service offered to one or more users with specific characteristics and capabilities, all immersed in an environment, and presented through devices with different features and functionalities.

- Metaphors and patterns: the way in which information is presented should facilitate rapid compression and synthesis, making use of design principles based on human perception and cognition. One way to achieve these principles is through patterns.
- Visualization pipeline: the model represents important elements involved in the visual mapping. Data sets are transformed into one or more visual representations, which are chosen, along with associated methods or interaction techniques.
- Methods and interaction paradigms: it is possible to interact with the visualization service by many different paradigms and techniques. The model has to represent these two features for providing the needed mechanisms to offer consistent information according to the devices that interact with the environment. Displays and other devices can be involved in the interaction processes through pointers, infrared sensors, RFID or NFC devices, among others.
- Structure and characteristics of the view: information is not usually displayed in isolation. On the one hand, visualization devices have graphical capabilities for displaying various types of contents at once. Moreover, providing a set of related contents makes the knowledge transmission easier and provides more information than the separated addition of all the considered contents.
- Social issues: visualization can be optimized depending on social user groups. At this point, we can observe the relationship between this model and the user model. The latter represents the relationships in the group, specifying the objectives and tasks, individual or grouped. Moreover, the user model reflects the fact that the individual users or groups can be located at the same place or in different places.
- Data characteristics: again, talking about the process of transforming the data sets to their visual representation, studying the data characteristics can improve the process: data source, type, data structure, expiration, truth and importance.
- Scalability: the amount of information required could be reduced by increasing the number of views and, therefore, growing the interactions. There are various techniques for information scalability. Some examples are zooming, paging, filtering, latency and scalability of complexity.

Figure 5 shows a simplified view of the information visualization ontology that represents the described-above issues.

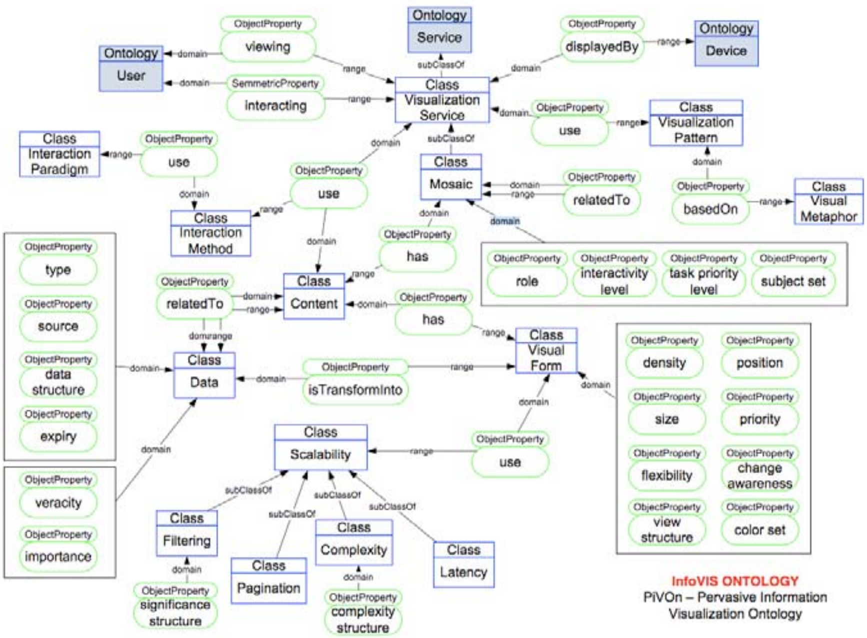

Figure 5: Information Visualization Ontology: a simplified representation.

4.4.2 Prototype: academic conference scenario.

Academic or scientific conferences are events compounded by activities whose participants have similar needs. Visualization services can be enabled to offer personalized information proactively. This prototype helped conference participants during the UCAMI, DCAI and IWPACBB Symposiums. Several information points were installed in the environment, including tactile screens and Near Field Communication readers to identify users.

The launched visualization services [see Fig. 6] had several functionalities:

- Access to personal information: users can access their profile and relevant personal documents (presentations and papers).
- Position maps: location-based service to offer itineraries to find relevant places.
- General information: the service matches time-awareness, schedule information and the user profile to offer personalized activities and events at the right time.
- Social issues: the system includes a service to locate users having similar scientific profiles in the environment. In this way, the social relationships were fostered.

Figure 6: Information visualization service views.

The proposed context model supports this visualization service. The context model is generic enough to represent the concepts involved in the scenario. However, this model generality makes necessary a specialization process that includes the domain-specific concepts. For example, the proposed context model includes, among others, the following classes: *User*, *Document* and *Event*. From these concepts, several classes have been included to describe the needs of the scenario, concretely, the *Topic* and *Paper* classes and the *author*, *userTopic*, *docTopic*, *paperTopic* and *paperSesion* properties. Figure 7 (left) shows these elements. Moreover, the device ontology has been specialized by including the hardware elements involved in the scenario (Figure 7, right).

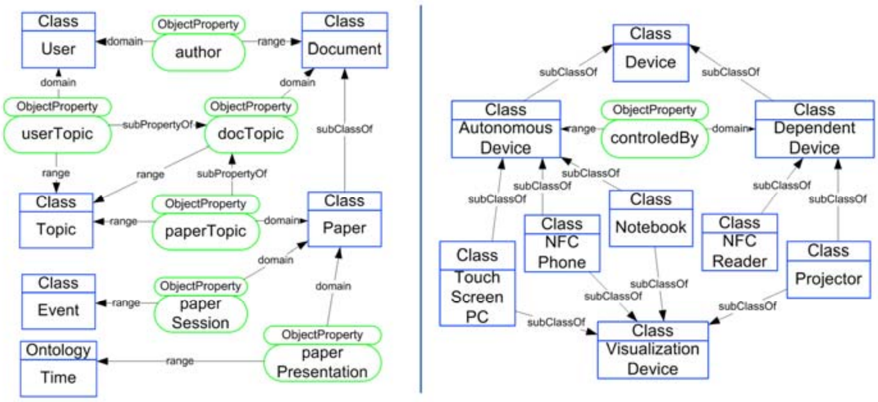

Figure 7: Specializations of the information visualization ontology.

An important functionality associated with the formal representation of context model is the inference mechanisms. The OWL context model enables reasoning engines based on description logics in order to endow the context-aware architecture with inference capabilities. Languages based on the description logics foundations allow us to apply the language semantics to obtain new information from previous information. Moreover, it is possible to combine description logics with rule-based systems to improve reasoning capabilities. Furthermore, reasoning techniques enable the definition of consistency rules, reducing the ambiguity in the context information, and thus maintaining and improving the information quality. The conference prototype defines several SWRL rules to adapt the system behavior to the situation changes. This language extends the semantics of the OWL axioms and follows the antecedent-consequent schema. Both the antecedent and consequent may be formed by a set of atoms that can be class descriptions, data ranges and model properties. Moreover, SWRL define several built-in operators (comparisons, math, Booleans, string and time operations). Concretely, Listing 1 shows some of these rules. First rule models the fact that a user identified by NFC and who is author of a paper to be presented in the near future, has consequently, the role of speaker. Second rule determines that a user must be notified when an interesting activity (based on his/her profile) is going to start. Finally, third rule enables personalized information retrieval based on user and document topics.

```
//Rule 1
LoginNFC(?x) & userIdNFC(?y,?x) & Paper(?p) &
author(?p,?y) & paperPresentation(?p,"nfut")
⇒  userRole(?y,"speaker")
//Rule 2
paperTopic (?p, ?y) & paperPresentation (?p, ?t) &
closer (?t, "now") & userTopic(?x, ?y)
⇒ Reminder(?r) & UserAgenda (?a) & consitOf
(?a, ?r) & define (?x, ?a)
//Rule 3
Content (?c) interacting(?x, ?c) & VisualForm (?v) &
has (?c, ?v) & Data (?d) & isTransformInto (?d, ?v)
& paper (?p) & source (?d, ?p) & paperTopic (?p, ?t)
⇒ userTopic (?x, ?t)
```

List 1: Inference rules to personalize the service behavior.

This section summarizes the relevant characteristics of the developed prototypes; however the scope of this manuscript is presenting the more theoretical issues of the ontological context model. Additional details of prototyped visualization services are provided in previous works [Bravo et al., 2006][Hervás et al. 2009].

5 Conclusions

In this paper we present a survey on context models and knowledge representation techniques to formalize these models. The classifications and taxonomies of the context elements have been analyzed and a general taxonomy has been proposed based on two dimensions, the Five W's theory and the four general elements: users, services, devices and environment. This was the starting point to define our context model, compounded by four ontologies.

The ontology formalization has been carried out by the Semantic Web languages due to the balance between expressiveness and computability offered by OWL. User models, device ontologies and environment formal description have been analyzed from the scientific bibliography. From this study, we have proposed a generic context model that includes relevant common concepts. Moreover, the model includes a sufficient detail level to apply the ontologies to multiple domains related to Ambient Intelligence. In the other hand, visualization information issues have been identified and transformed into ontological classes and properties. This formal model enables a proactive and interoperable behavior of visualization services.

The benefits of this kind of formal knowledge representation have been exemplified by a specific prototype for academic conference scenarios. The prototype includes personalized and context-powered services enhanced by reasoning techniques through inference rules.

As a summary, we propose and apply a generic context model powered by formal ontological representation techniques, balancing opposite concepts: expressiveness and computability on the one hand, and generality and detail level on the other hand. Focusing on this second issue, the described prototype reuses up to 74% of elements included in our context model. Moreover, the specialization process has ensured the definition of 24 new ontological elements, 7% of the whole model. Similar values have been obtained in the model adaptation to other scenarios, such as mobile patient monitoring and nursing daily task support.

Acknowledgements

This work has been financed by PII1I09-0123-27 and HITO-09-50 projects from *Junta de Comunidades de Castilla-La Mancha*, and by the TIN2009-14406-C05-03 project from the *Ministerio de Ciencia e Innovación* (Spain)

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