Ontology-Based Management of the Telehealth Smart Home, Dedicated to Elderly in Loss of Cognitive Autonomy

Fatiha Latfi[1], Bernard Lefebvre[1] and Céline Descheneaux[2]

[1] Laboratoire GDAC, Département d'informatique
Université du Québec À Montréal (UQÀM)
Case postale 8888, succursale Centre-ville
[2] Laboratoire DOMUS, Université de Sherbrooke
Québec, Canada

Abstract. Taking care of an elderly in loss of cognitive autonomy is a challenging task. Artificial agents, such as the Telehealth Smart Home (TSH) system can facilitate that task. However, the design of such a system is, in itself, a challenging task as well. In this paper, we present an ontology-based model of the TSH, which is designed in a modularized approach and implemented in OWL using Protégé2000. Our main goal is to take advantage of the full potential of ontologies to describe the domain, in order to provide an effective base for the development, the configuration and the execution of software applications. As an example, instantiations of the ontologies of the TSH are needed to initialize the Bayesian networks used to recognize the activity the patient is probably performing. They are also involved in the learning process of the life habits of the TSH's occupant, and in the system maintenance.

Key words: Ontologies, Telehealth Smart Home, OWL, Protégé2000

1 Introduction

1.1 Ageing and Alzheimer

Rapid ageing of the World population has been one of the major causes of concern over the last decade. Fortunately, recent progresses made in the field of cognitive ageing now allow earlier detection of various pathologies related to ageing. Early detection, in turn, makes it possible to better prepare for the following stages of the diseases and will, one day, perhaps help in finding a cure for some and/or all of them. However, even if these researches offer partial solutions and can prove to be helpful in alleviating some of the pain and distress caused by such diseases, pathologies related to the ageing process still remain a major preoccupation in today's society and Alzheimer's disease is, by far, one of the most worrisome age-related cognitive disease of all. If ageing is a phenomenon that can be classified as "deeply dynamic" by [14], requiring continual adaptations between the elderly person and his relatives, in the case of Alzheimer's, the dynamic aspect and continual adaptation are even more crucial. The life of a person suffering from Alzheimer's is literally governed by the disease which keeps on progressing as time goes on. As the disease progresses, the subject becomes more vulnerable and finds it harder and harder to adapt to new situations, even very simple ones.

1.2 Telehealth Smart Home

The Intelligent Habitat in Telehealth system [12], also known as Telehealth Smart Home (TSH) can provide solutions for this adaptability. The main goal of the TSH is to provide assistance to the patient in order to prevent any potentially dangerous situation that could endanger his life.To achieve this objective, the TSH system relies on several physical and software components, supervised by various individuals such as a nurse, a relative, the family doctor, the system manager, etc. In order to be effective, such a system should have an adequate representation of basic knowledge, a good inference module and finally, a good HMI (Human Machine Interface) for an effective communication between the system and its users.

1.3 TSH Challenges

The challenges related to the TSH are twofold. First, an adequate model of what a smart home designed to care for someone with loss of cognitive autonomy has to be described with comprehensive ontologies. Second, those descriptions/definitions have to be done by using an expressive language such as OWL [9].

Adequate Representation. One of the key roles of a representation is to be a substitute [3] for the real object we want to handle. A good representation makes it also possible to perform various reasoning algorithms in order to infer new knowledge in order to reflect as accurately as possible the future evolutions of the world under study. However, to ensure the correctness of such knowledge, we need a basic model that is as much representative of reality as possible. Producing such an adequate model has always proven to be a challenge for anyone interested in modeling part of the real world. The fact that we have to find ways to represent elements and concepts related to individuals suffering from a degenerative disease, such as Alzheimer's, that keeps on evolving for the worst makes that task even more daunting.

Adequate Communication. In addition to the need for adequacy related to the representation of the field, the intelligence of the system lies also in the interaction between the various users and this representation. This interaction is a major feature of a TSH system. It needs to provide an effective way of displaying the information, which must allow the user to correctly perceive the message conveyed by the interface. This kind of visualization can be found in domains such as Human-Machine interfaces, Data-Mining, image processing, graphics. It

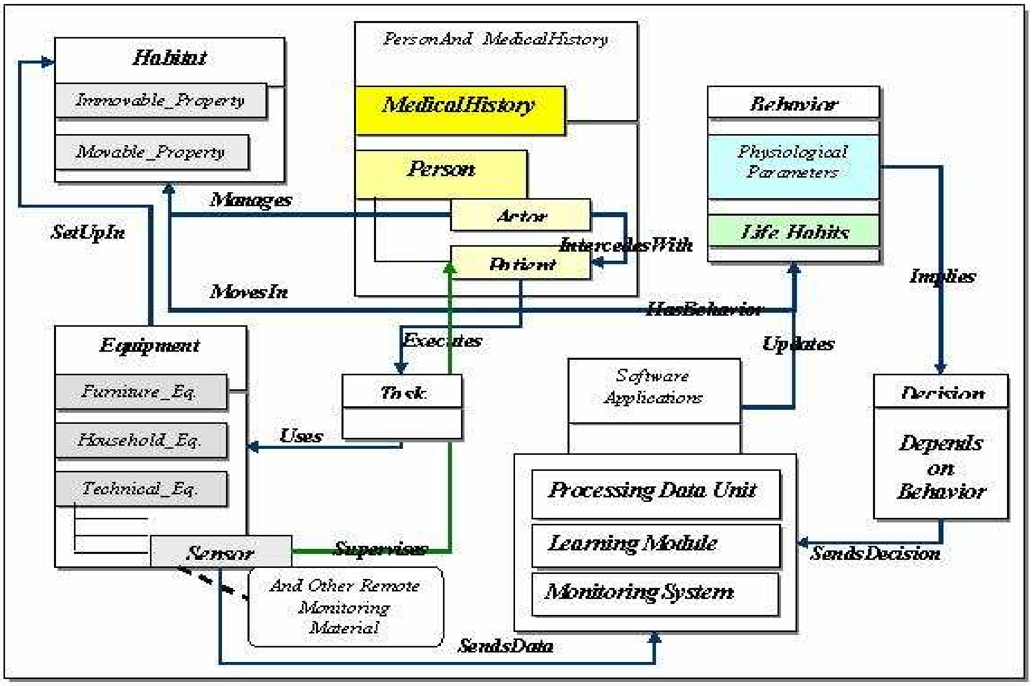
is thus an inter and multi disciplinary field of research [2], which is of the most interest.
Modeling the system with the use of ontologies makes it possible to help providing an adequate representation and an adequate communication.

Ontologies. Ontologies are not only used to describe the real world. They demonstrate their full potential when being used [9] as an effective support for the development as well as the configuration of software applications, since they allow an optimization of the quality cost ratio [13]. Since the occupant of the habitat is an individual, usually elderly, in loss of cognitive autonomy, ontologies must also adequately support the human machine communication[9] whose role is to enable the interfaces to adapt and adjust themselves in accordance with the characteristics of the patient. Our first goal is to build an ontological model that is as comprehensive as possible. The ontologies taking part in the model are presented in the next section.

2 Ontological Architecture of TSH

The approach we use to design our architecture consists in partitioning the domain into sub-domains in order to take advantage of the Divide and Conquer principle. The different ontologies are defined individually in a first step with the Protégé-OWL editor [3] and organized in a global structure [7] using the OWL imports statement. A set of properties (called *meta-relations* and summarized in figure 1) is defined to describe the relationships between the ontologies.
Seven ontologies are part of the model. The Habitat ontology describes the structure of the accommodation (the housing facility in which the patient lives: rooms, doors, windows, etc). The PersonAndMedicalHistory ontology gives a description of the person who needs care and his medical history. It is also dedicated to the person whose role is to ensure this care and what are its various duties. The Equipment ontology defines the equipment that can equip the Smart House and be involved in the system. The Software applications ontology describes the modules of the system in such a way that they can be reused or understood. The Task ontology details the tasks the patient, the actor and the system are supposed to achieve. The Behavior Ontology addresses 2 important aspects in the context of remote monitoring, the life habits and critical physiological parameters. Finally, the Decision ontology is closely related to the behavior when a critical situation or a change of habits is detected. A mapping system like the medical model Symptoms-Diagnosis, can be adapted to the problem of decision making, when a particular number of facts (especially a critical behavior), corresponds to a decision to be taken. This decision can quite simply consist in doing nothing or be concretized in an action, whose type depends on the gravity of the situation [8].
The architecture is shown in figure 1. In the next sections we will present the PersonAndMedicalHistory and the Equipment ontologies.

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



Property	Domain	Range
Executes	Patient	Task
HasBehavior	Patient	Behavior
MovesIn	Patient	Habitat
Manages	Actor	Habitat
Implies	Behavior	Decision
IntercedesWith	Actor	Patient
SendsData	Equipment	SoftwareApplications
SendsDecision	Decision	SoftwareApplications
SetUpIn	Equipment	Habitat
Supervises	Equipment	Patient
Updates	SoftwareApplications	Behavior
Uses	Task	Equipment

Fig. 1. TSH Ontological Architecture and Meta-relations

2.1 The PersonAndMedicalHistory Ontology

In the framework of the TSH, the ontology of the person is composed of two main parts: the first one relates to the person and the second one relates to the medical history of the patient. The part in charge of describing the person is divided into two sub-parts. The first sub-part describes the profile of the person living in the TSH (the Patient), whereas the second part describes the various persons (called Actors) in charge of ensuring the correct operation of this habitat. An actor can be an individual (human being) or a legal entity. Three types of actor are defined in this ontology.

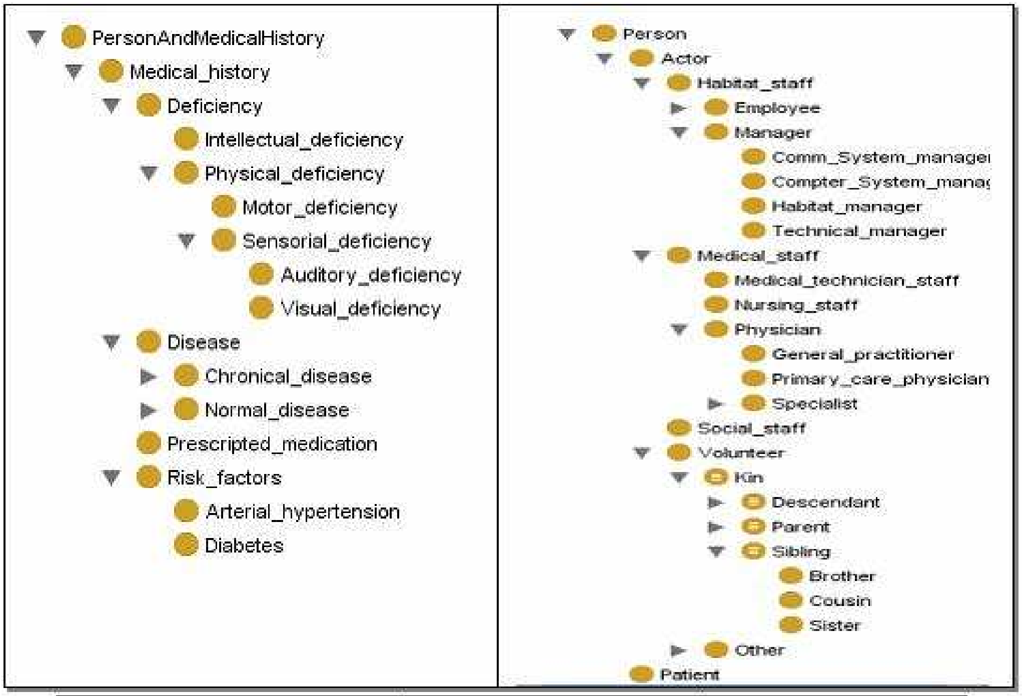
1. A medical actor (Medical-staff) who describes all the people who are able and likely to intervene in one way or another in order to insure the physical and/or mental health of the patient;
2. The actor described by Habitat-staff is involved in the management of the habitat;
3. The third type of actor describes everyone who can interact in a social manner with the patient living in the TSH. They can be close relatives or simple volunteers.

The second class entitled Medical-history describes the medical history of the patient as well as the various risk factors which are either related to Alzheimer's disease or to other age-related diseases. These diseases can be temporary or chronicle, mental or physical. Four great classes are located in the left part of the figure. The Deficiency class describes all deficiencies (Intellectual-deficiency, Physical-deficiency) that can afflict the patient. The Disease class lists the various pathologies (past and present) exhibited by the patient. This will make it possible to make a follow-up of its health and to better know and understand some of its actions or abnormal behaviors. The class Prescript-medication allows the system to instantiate the hygiene and medication rules to be applied to the patient. Finally, the Risk-factors class gives a description of diseases considered as possible triggering factors for Alzheimer's disease. In the case of the TSH, the patient is already a person suffering from Alzheimer's and thus these diseases, such as Diabetes or Arterial-hypertension can be considered as potentially existing and their detection is thus very important.

2.2 The Equipment Ontology

This section gives a short description of the Equipment Ontology [4] which is an important part of the ontological architecture of the TSH. It contains the description of all pieces of equipment that can be found in the habitat in order to ensure the patient safety. This ontology, diagrammed in figure 3, is defined in three main parts, which are the ***furniture equipment***, the ***household equipment*** and the ***technical equipment***.

[4] This ontology is detailed in [7].



Property	***Domain***	***Range***
hasSensorialDeficiency	Patient	Deficiency
hasToContact	General_practitioner Primary_care_physician	Specialist Social_staff Kin Volunteer
hasDescendant	Patient	Descendant
hasSibling	Patient / Sibling	Patient / Sibling
isResponsibleOf	Manager	

Fig. 2. PersonAndMedicalHistory Ontology: Screenshot of Main Classes and Some Object Properties

3 How do Ontologies Make the System be Intelligent?

Taking care of someone in loss of cognitive autonomy is a daunting task, which requires huge efforts and a lot of flexibility from the caregiver. The design of the knowledge part is in consequence a challenge. To be efficient, the system must be able to answer questions such as: is the patient safe or is he at risk? The knowledge base and how it is represented play an essential role in the answer. Ontologies, *as rigorous descriptive models* [13], are appropriate for this task.

3.1 The Use of the Ontologies

Ontologies are used in order to initialize the system. At first, the ontologies have to be instantiated and then, these instances are used to initialize the various Bayesian Networks that are part of the activity recognition and learning module in charge of recognizing activities being performed by the TSH occupant and in the learning his life habits[4].

Instantiation of the Ontologies. This instantiation concerns first the Habitat ontology. For a given habitat, a configuration of equipment is defined which corresponds to an instantiation of the three main classes of the corresponding ontology. It is then possible to know what pieces of furniture are present in the habitat, which pieces of equipment are located in each part of the house/apartment and especially which equipment are used to forward data to the system. The basic acquisition of data is realized by sensors (elements of the Technical-equipment class). Some of these sensors are dedicated to the detection of activities but others concern the monitoring of biological parameters related to the patient. At a later stage and after being processed by learning components of the system, these data will permit the instantiation of health and behavior parameters by the means of the Behavior Ontology as well as the two classes Patient and MedicalHistory of the PersonAndMedicalHistory Ontology. The instantiation of the Actor class also makes it possible to specify which people will be in charge of the Habitat and the caring of the patient. Finally, the instantiation stage also relates to the Task ontology as well as the Decision ontology.
This stage is followed by the initialization of Bayesian Networks.

Initialization of the Bayesian Networks and the Learning Steps. In this second stage, Bayesian Networks are used for recognizing which activity is most likely to be performed by the patient at a given time and in a given place [4]. This recognition is the initial step in the process that will enable us to learn the patient's life habits, follow the evolution of his cognitive disorder, and detect/prevent possible emergency situations. Several factors (such as the time of day, the location of the patient, the patient's level of activity, the previous activity that was performed, etc.) have to be taken into account in order to deduce as accurately as possible what is the most likely activity being performed. The structure of the various Bayesian networks also takes into account those factors. There is a hierarchy of Bayesian networks which is closely related to the hierarchy of activities. At the lower level are specialized networks devoted to the recognition of simple activities such as the ones which can take place in the bathroom in front of the wash basin. The structure of these networks is defined using the instances of the corresponding ontologies.

These two stages are essential if we want the system to be able to monitor the patient and learn what his life habits are. This learning process is also achieved by upper level Bayesian networks in a generalization process which feeds and updates the Behavior Ontology and consequently the decision Ontology [8].
The two stages are illustrated by figure 3.

3.2 How can Ontologies help the User Interface to be Intelligent?

The concept of intelligence always causes much controversy. According to [6], the intelligent species is that which survives by constantly adapting itself, contributing thus to its own perpetuity. Don Norman said in [10]: "*Do we need intelligent interfaces? I don't think so: The intelligence should be inside, internal to the system.*"
The problem of developing "intelligent" user interface has become (been) a worrying topic for the research community in recent times. Furtado [5] and Puerta [11] have already presented some ontology-based methodologies to produce or develop good user interfaces.
Let's explain how ontologies can help the user interface to be intelligent by a simple example. In the PersonAndMedicalHistory Ontology, we have a class called ***Deficiency***. When instantiated, this class gives the list of all deficiencies that affect the patient. If the ***Visual-deficiency*** instance has a value, it means that the patient's sight can be partially or totally affected. Even if the patient sight's loss is very minimal, the user interface must adapt itself in order to compensate. Conversely, if the patient suffers from an ***Auditive-deficiency***, the user interface must be centered on visual effects. This can be ensured by a visual metaphor [1]. The user interface is defined and configured using the SoftwareApplications Ontology and the Patient profile described in the PersonAndMedicalHistory which is in turn updated by the others ontologies (especially the Behavior Ontology) and the learning module.

4 Conclusion and Future Work

In this paper, we presented an overview of an ontology-based model of the Telehealth Smart Home (TSH), dedicated to elderly in loss of cognitive autonomy.
We use Ontologies for their full potential to support effectively the development as well as the configuration of software applications. We also use Ontologies for their potential to support adequately human-human and human-machine communication.
The development of such a system needs a strong process of validation, which

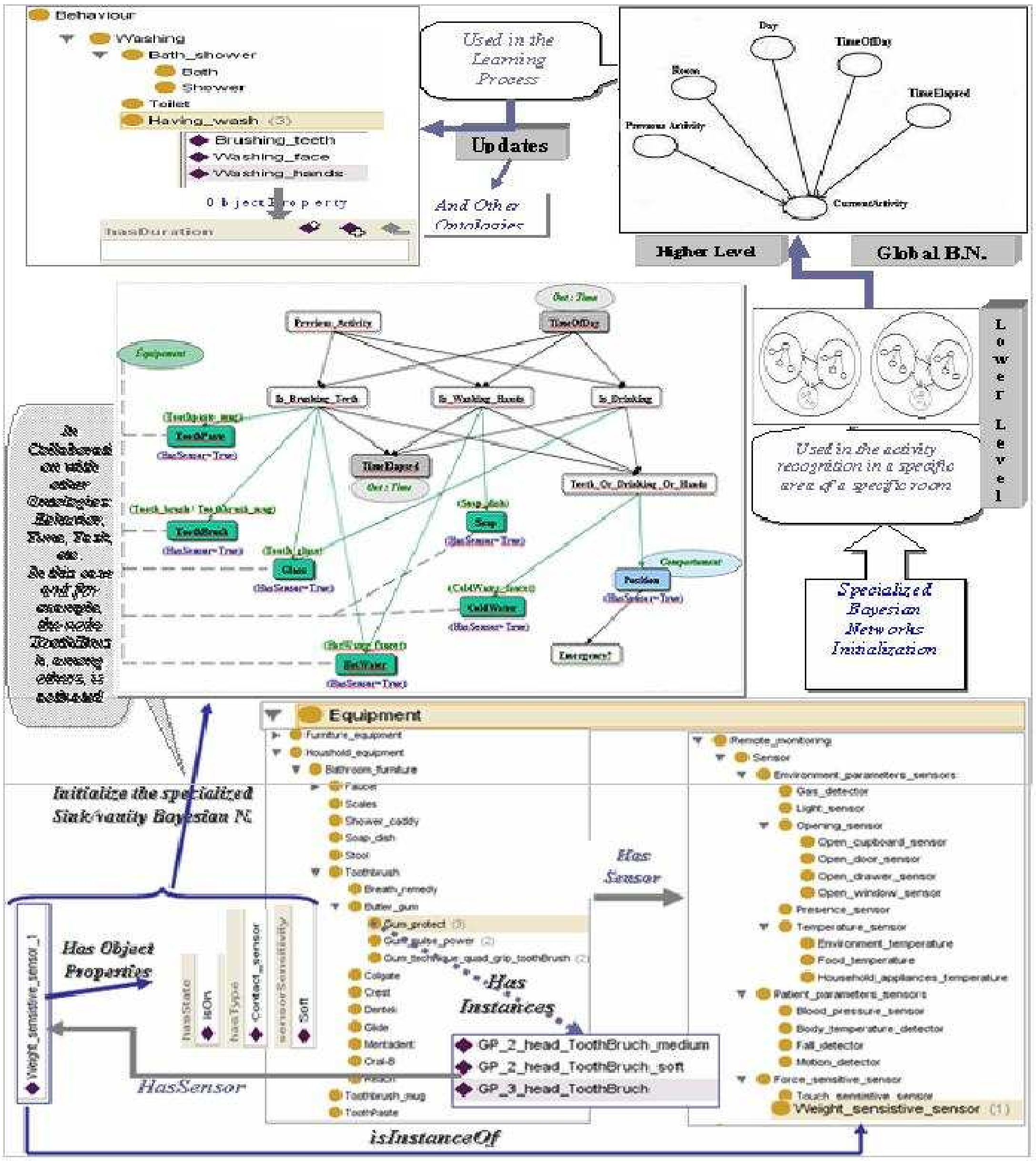


Fig. 3. Instantiation Ontologies and B.N. Initialization Example

will be achieved in collaboration with the DOMUS laboratory. [5] team and the AFIRM [6] team.

Acknowledgment. This work was conducted using the Protégé resource, which is supported by grant LM007885 from the United States National Library of Medicine.

References

1. Bonhomme C., Aufaure-Portier M., Trépied C.: Metaphors for Visual Querying of Spatio-Temporal Databases. In: R.Laurini (Ed): Visual 2000, LNCS Vol. 1929, Springer-Verlag Berlin Heidelberg (2000) 140-153
2. Chaomei C.: Information Visualization. In: Information visualization. Editorial. Palgrave Macmillan Ltd. (2002)1, l - 4
3. Davis R., Shrobe H., Szolovits P.: What is a Knowledge Representation? In: AI -Magazine. (1993) 14(1):17 - 33
4. Descheneaux C., Latfi F.,Lefebvre B., Activity Recognition in a Smart Environment. Accepted to FICCDAT Toronto, Canada (2007)
5. Furtado E., Furtado J., Silva W., Rodrigues T., Taddeo L., Limbourg Q., Vanderdonckt J.: An Ontology-Based Method for Universal Design of User Interfaces. In: Proceedings of Workshop on Multiple User Interfaces over the Internet: Engineering and Applications Trends. Lille, France (2001)
6. Grisar, T.: Le déterminisme biologique et social du concept d'intelligence: la signification évolutive de l'intelligence humaine. In: Aped, L'école démocratique (2002)
7. Latfi F., Decheneaux C., Lefbvre B.: Habitat Intelligent en Télésanté: Ontologie de l'Équipement. Accepted to FICCDAT Toronto, Canada (2007)
8. Latfi F., Lefebvre B.: A cognitive system for a Smart Home Dedicated to People in Loss of Autonomy. In: From Smart Homes to Smart Care. ICOST2005. IOS Press. Magog, Quebec. (2005) 245-254
9. Lutz C., Baader F., Franconi E., Lembo D., Moller R., Rosati R., Sattler U., Suntisrivaraporn B., Tessaris s.: Reasoning Support for Ontology Design. In: Proceedings of the OWLED*06 Workshop on: OWL: Experiences and Directions. Vol.216. Athens, Georgia (2006)
10. Norman D., Complexity versus Difficulty: where should the Intelligence be? In: Proceedings of the 7th International Conference on Intelligent User Interfaces. San Francisco, California,USA (2002) 4-4
11. Puerta A., Erickson H., Gennari J., Musen M. : Model-Based Automated Generation of User Interfaces. In: International Conference on Intelligent User Interfaces. San Fransisco, California, USA (1997) 65-72
12. Rialle,V.et al.: Smart Home:Information Technology for Patients at Home.In: Telemed Journal and E-Health 8, n0. (2002) 4:395-409
13. Tetlow P., Pan J.Z., Oberle D., Wallace E., Ushold M., Kendall E.: Ontology Driven Architectures and Potential Uses of the Semantic Web in Systems and Software Engeneering. In: W3C Working Group, Editors Draft (2006)
14. Vercauteren R. et al.: Pratiques Gérontologiques. Une Architecture Nouvelle pour l'Habitat des Personnes Âgées. In: Édition Éres. Ramonville Saint-Agne (2001)

[5] http://www.domus.usherbrooke.ca/, Sherbrooke, Quebce, Canada
[6] http://www-timc.imag.fr, Grenoble, France