Ontology and Rules-Based Model to Reason on Useful Contextual Information for Providing Appropriate Services in U-Healthcare Systems

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Abstract. In our days, the development of computing technologies has facilitated the daily life since the environment is improved by its different applications. Pervasive computing is one of the most efficient computing areas which offer several smart systems aiming to provide various significant services in our life. Context awareness, in general and context-aware adaptation in particular, is a central aspect of pervasive computing systems, characterizing their ability to adapt and perform tasks based on context. In this paper, we describe our proposal ontology and rules-based model for representing and reasoning on useful contextual information. This model permits to provide appropriate services in ubiquitous healthcare systems which are one of the main application areas for pervasive computing that allow monitoring the health and wellbeing of patients anytime and anywhere.

Keywords: Pervasive computing, U-Healthcare, context-awareness, context modeling, context reasoning, ontology, inferences rules.

1 Introduction

Ubiquitous or pervasive healthcare (U-Healthcare) systems are one of the main application areas for pervasive computing [1] that allow monitoring the health and

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wellbeing of patients anytime and anywhere; using intelligent environments technology which include sensors, services and smart mobile devices. This kind of system must provide us not only medical services but also services that allow controlling the daily activities of patient at his own home such as his shower, and controlling his physical environment such as home temperature. However, obstacles related to the limited resources of mobile devices like battery lifetime; privent the service continuity in this kind of systems which use mobile devices.

In order to provide the appropriate service to the user, the pervasive healtchare system must be able to gather contextual information over time which comes from different and heterogeneous sources, then to react rapidly by analyzing and reasoning dynamically not only on the health measurements of patient, but also on his current location, his profile, his physical environment and his devices'constraints. This makes context-awareness in general and context-aware adaptation in particular, an essential requirement for pervasive computing systems. One of the greatest challenges of pervasive computing is to model context information. Context modeling permits to represent contextual information and provide a high level of conceptual abstraction which allows reasoning on this information in order to adapt the behavior of system. Therefore, there is an increasing need to construct a uniform context model due to the diversity of contextual information sources. According to [8], ontologies seem to be one of the most suitable solutions for modeling context; due to their high and formal expressiveness and the possibilities for applying ontology reasoning techniques. ontology [13] can be defined as a formal explicit definition of a shared conceptualization which permit to provide general expressive concept and support for syntactic and semantic interoperability. In addition, their amenability for building context-aware pervasive computing systems is demonstrated in several works [14] [15] [16] [17]. In this context, we aim to propose a scalable ontology for modeling and reasoning not only upon patient's health measurements which can be gathered from different bio-sensors such as blood sugar measurement, but also for reasoning on all useful contextual information in order to provide the appropriate healthcare services and also the appropriate smart home service that allows patients and elderly persons to live safely and independently in their own homes. In addition, our ontology takes into consideration the limited resources of mobile devices and supports solutions that can be proposed by the developer for assuring the continuity of services, such as the migration of services into other devices or into the cloud when mobile devices cannot support services because of their resource constraints like battery lifetime.

The rest of the paper is organized as follows. Section 2 discusses some existing works. Section 3 presents our ontology and rules based-model. Finally, Section 4 concludes the paper and describes future work.

2 Related Works

Several interesting works are proposed in the field of pervasive healthcare system, which have demonstrated the amenability of ontologies for building context-aware pervasive computing systems. Catarinucci et al [14] have proposed a context-aware infrastructure for ubiquitous and pervasive monitoring of heterogeneous healthcare-related scenarios. Their system is based on ontology representation, multi-agent paradigm and rule-based logic. They have used an ontology and inference rules for modeling and reasoning on context information. In the work [15], authors proposed a u-healthcare service system and an ontology-based healthcare context information model to implement a ubiquitous environment. In the other work [16] an ontological model for organizing the knowledge in the heterogeneous domain of embedded devices and complex healthcare systems has been proposed. This ontology covers the domain of medical services where the medical services cover many areas such as patient care, clinical and administrative decisions, assisting devices and patient diagnostics. In [17] authors have proposed an intelligent context-aware system based on ontology which can be reused in any system uses bio context in pervasive environment. However, these works have not taken into consideration the limited resources of mobile devices such as battery lifetime of smart phone. In addition, all these works are based on healthcare or medical services. They don't take into account other interesting services that allow patients and elderly persons to live safely and independently in their own homes such as controlling home temperature and water temperature.

3 Our Ontology and Rules-Based Context Model for Pervasive Healthcare Systems

In our work, we propose ontology and rules-based model for representing and reasoning upon useful contextual information that must be taken into consideration for providing appropriate services in order to allow monitoring the healthcare of patient anywhere and anytime. Our ontology takes into account the limited resources of mobile devices and supports solutions that can be proposed by the developer to ensure the service continuity, such as the migration of services into other devices or into the cloud; when mobile devices cannot support services because of their resource constraints as battery lifetime. Before describing our ontology, we take a simple motivating scenario.

3.1 Scenario

Mr. Adem is an elderly diabetic person who lives alone at home and needs to monitor his health. He uses an intelligent environment which includes smart devices, sensors and services that are deployed on his smart phone. This intelligent environment constructs a pervasive healthcare system that allows him to live safely and independently within his own home. Let's take some examples of services of this system:

When Mr Adem needs to check his blood sugar level, he uses a bio-sensor connected to his smart phone via Bluetooth technology. According to his blood sugar level, the system will provide him the appropriate service. If his blood sugar level is out of the normal range determined by his doctor, there will be three possible cases:

- *High Blood Sugar level:* in this case the health situation of person is not in danger, but he has a high blood sugar level and he must take an insulin injection. The system will execute the "AdjestingInsulinDose" service which adjust automatically the insulin dose according to the blood sugar measurement, and execute the "Diabetes-Guide" which contains a guide about what must do as exercises and diet; for keeping his blood sugar level in normal.
- *Low Blood Sugar level:* in this case, the system will execute the "Diabetes-Guide" which contains a guide of what he must to do for adjusting his blood sugar level.
- *Danger Blood Sugar:* in this case, his health situation is in danger, he must be transferred to the nearest emergency center or hospital. The "Emergency" service must be executed in order to contact the hospital and sends a brief report contains the health situation of person and his personal information.

Mr Adem wants to take a shower, when he inters in his bathroom and activates the faucet; "Adjusting water Temperature" service will be executed automatically for adjusting the temperature of water.

At 20 o'clock, he should take his dinner and his drugs, but he often forgets it. For that, the system executes the "Drug Reminder" service for reminding him about the list of drugs and foods that can be taken in dinner.

3.2 Context Modeling

Context information can be characterized as static or dynamic [7]. Static context information describes the invariant information that can be obtained directly from users such as personal information. Dynamic context information describes the variant information that can be captured from different sensors such as blood pressure and location. Ubiquitous healthcare systems focus generally on dynamic context since they need to adapt their behaviors dynamically according to the change of this context. However, that does not prevent to take into account the static context such as chronic disease for reasoning on health situation of patient. In this context, we construct an ontology that can be used for modeling useful contextual information (static and dynamic context) in pervasive healthcare systems. In fact, Ontologies are used to capture knowledge about some domain of interest; like in our works; pervasive healthcare domaine. Our ontology describes the concepts in this domain and also the relationships that hold between those concepts.

Ontology Classes

In ontology, classes are a concrete representation of concepts. As shown in Fig. 1, our ontology is composed of four general classes that represent cocepts of useful contextual information that are necessary for monitoring the healthcare situation of elderly persons in their smart homes or anywhere and anytime. These classes are; "Personal Data" class, "Sensor Data" class, "Services" class and "Host" class.

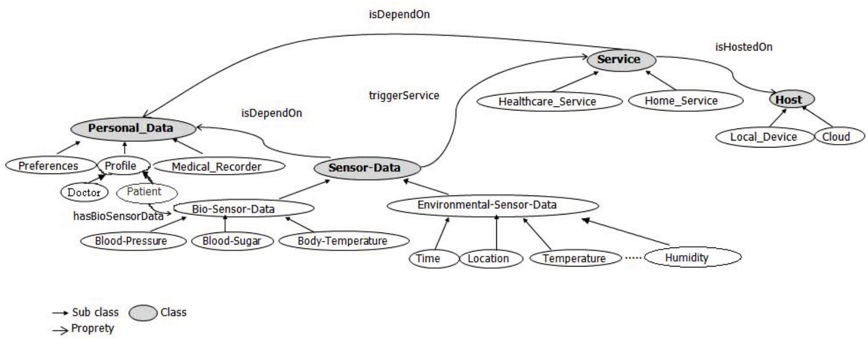

Fig. 1 Our Ontology structure

- The *Personal Data* class represents user's personal information that can be specified manually by the user; such as his profile, his medical information and his preferences.
- The *Sensor Data* class represents data that can be gathered from different sensors. We have two types of sensor data: i) Bio-Sensor Data represents data captured by Bio-Sensors, like blood pressure, blood sugar and body temperature. ii) Environmental Sensor Data represents data captured by environmental sensors, like time, location, temperature, etc.
- The *Services* class represents services that can be provided by the pervasive healthcare system. As we discussed in previous sections, pervasive healthcare systems must provide not only healthcare services, but also provide services that allow patients to live safely and independently in their own homes. For that we have created two sub classes of Service class; Healthcare Service class represents

Table 1 Exemples of Object Properties

Object Property	Source class (Domain)	Target class (Range)
triggerService	Sensor-Data	Service
isDependOn	Sensor-Data Service	Personal-Data
isHostedOn	Service	Host
useHost	Patient	Host
hasBioSensorData hasBloodSugar hasBloodPressure	Patient	Bio-Sensor-Data
hasMedicalRecorder hasChronicDisease hasDrugs	Patient	Medical-Recorder

all healthcare services such as Diabetes Services, Drug Service, Emergency Service, etc, and Home Service class represents services that allow monitoring the daily life of patients in thier smart home such as AdjustingWaterTemperature Service. All these services can be triggered by Sensor Data.

- The *Host* class represents different hosts of services proposed by developers. For instance, services can be hosted on Local Devices or on Cloud. The Local Device class contains all information about Fixed Devices and Mobile Devices. Mobile Devices have limited resources such as battery, memory and CPU. The Cloud class contains information about the cloud that can be used for hosting services.

Ontology Relationshipes

Relationships indicate the interaction among the concepts in the ontology. They are defined by the properties and by the attributes that characterize the classes. Relationships that hold between classes are called "Object properties". Each object property has source and target. Table 1 represents examples of object properties and their source/target classes that we had defined in our ontology. Some of these properties have sub-properties, e.g "hasBloodSugar" property is a sub-property of "hasBioSensorData". Other object properties such as "isMegratedOn" property can be inferred by using inference rules. Attributes that characterize the classes or the instances of classes are called "data type properties". They describe relationships between instances (individuals) of classes and data values. Table 2 presents examples of data type propreties. Like object properties, these properties can also have sub-properties such as "hasBloodSugarValue" which is sub-property of "hasBiosensorDataValue" data type property.

Ontology Language

The literature offers many languages to represent or express ontologies, including resource description framework schema (RDFS), DAML+OIL, and OWL. OWL is a key to the semantic web and was proposed by the Web Ontology Working Group of W3C [18]. OWL is a general purpose ontology language that contains all the necessary constructors to formally describe most of the information management definitions: classes and properties, with hierarchies, range and domain restrictions; that's whay we have used OWL language for describing our ontology.

Example of OWL Language

```
</owl:Ontology>
    </owl:Class>
    <owl:Class rdf:ID="Bio_Sensor_Data">
        <rdfs:subClassOf rdf:resource="#Sensor_Data"/>
    </owl:Class>
    <owl:Class rdf:ID="Blood_Pressure">
       <rdfs:subClassOf rdf:resource="#Bio_Sensor_Data"/>
    </owl:Class>
    <owl:Class rdf:ID="Blood_Sugar">
       <rdfs:subClassOf rdf:resource="#Bio_Sensor_Data"/>
       ...............
```

Table 2 Exemples of Data type Properties

Class	Data type Property	Data Type
Profile	hasProfileInformation hasName hasDateOfBirth	 string date ....
Bio-Sensor-Data	hasBiosensorDataValue hasBloodSugarValue	integer
Bio-Sensor-Data	hasBiosensorDataLevel hasBloodSugarLevel	string
Blood-Sugar	isBeforMeal	Boolean
Mobile-Device	hasBatteryLevel	integer

Table 3 Exemples of SWRL Rules

Physician Rules	Blood-Sugar(?x)⋀Patient(?p)⋀ hasBloodSugar(?p,?x) ⋀hasChronicDisease(?p,Diabet-Type-1)⋀ hasBloodSugarValue(?x,?y) ⋀isBeforMeal(?x,true) ⋀ swrlb:greaterThanOrEqual(?y,500) ⟶ hasBloodSugarLevel(?x,"Danger")
Developer Rules	Blood-Sugar(?x)⋀Patient(?p)⋀ ⋀hasBloodSugar(?p,?x)⋀hasBloodSugarLevel(?x,"Danger") ⋀Emergency-Service(?s) ⟶ triggerService(?x,?s)
	Patient(?p)∧Mobile-Device(?mobile)∧useHost(?p,?mobile) ∧Service(?s)∧isHostedOn(?s,?mobile)∧ hasbBatteryLevel(?mobile,?batterylevel)∧ swrlb:lessThanOrEqual(?batterylevel,15) ∧Cloud(?cloud)∧useHost(?p,?cloud) ⟶ isMigratedOn(?s,?cloud)

3.3 Context Reasoning

The main objective of proposing our ontology is not only to represent useful contextual information, but also to allow reasoning on this information using inference rules of the form "if...then...". Inference rules are a set of rules which define a general mechanism for discovering and generating automatically new relationships between concepts, based on existing ones [19]. In our ontology we use a set of inference rules for deducing services that will be triggered by sensor data and then which service will be provided to the user. We have classified our rules in two categories; Physician Rules and Developer Rules.

- *Physician Rules* are a set of rules related to the health situation and they are specified by a doctor and not by a developer. These rules permit to reason on Bio-sensor Data for deducing the health situation of person.

Example 1; *IF* (Blood sugar value is more than 500 m/l) *THEN* (blood sugar level is Danger).

- *Developer Rules* are specified by the developer. The developer defines a set of rules that permit to adapt the behavior of system in order to provide appropriate services according to the situation of person and to assure the continuity of services.

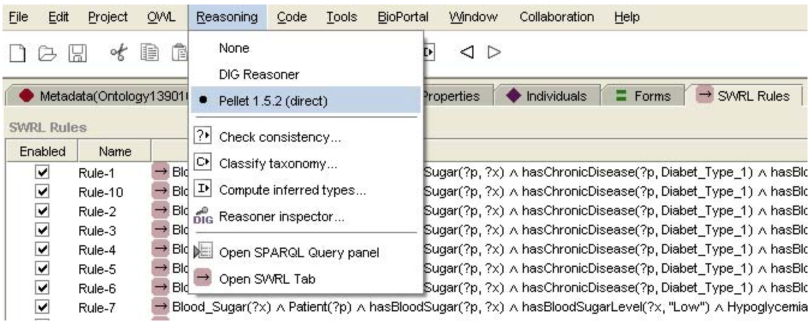

Fig. 2 Part of Our SWRL Rules on Protege

Example 2; *IF* (Patient has Danger blood sugar level) *THEN* (trigger Emergency service).

Example 3; *IF* (Service isHostedOn Mobile Device) *AND* (Battery Level is less than 15 percent) *THEN* (Service isMigratedOn Cloud).

For applying these rules on our ontology, we need to express them by a semantic language. The Semantic Web Rule Language (SWRL) is a proposed language for the Semantic Web that can be used to express rules as well as logic, combining OWL with a subset of the Rule Markup Language. SWRL [20] extends the set of OWL axioms in order to include conditional rules (Horn clauses), of the form if... then.... In fact, a rule axiom consists of an antecedent and a consequent. In the "human-readable" syntax of SWRL, a rule has the form:

$$\text{antecedent} \Rightarrow \text{consequent}.$$

Informally, a rule may be read as meaning that if the antecedent holds (is "true"), then the consequent must also hold. Table 3 represents some examples of our SWRL rules used in our work.

As represented previously, we can perceive that our ontology is not complex to implement and can cover all useful cotextual information. In addition, our ontology and rules-model is scalable because we can easily add new contextual information and reasoning upon this new information, for instance, if a new sensor is added to the environment, like a heartbeat sensor, we can add this information by just changing the ontology structure and creating new rules for this information.

3.4 Ontology Implementation

For building our ontology and SWRL rules, we have used the Protégé tool [21]. Protégé is a free, open-source platform that provides a growing user community with a suite of tools to construct domain models and knowledge-based applications with ontologies. At its core, Protégé implements a rich set of knowledge-modeling structures and actions that support the creation, visualization, and manipulation of ontologies in various representation formats including OWL, RDF(S), and XML Schema. Using SWRL Tab and Pellet reasoner [22], we have created and tested our rules on the ontology; as showen in Fig.2.

4 Conclusion

Ubiquitous healthcare systems are one of the main application areas for pervasive computing which aim to provid several services; that allow monitoring the health and wellbeing of patients anytime and anywhere. For being able to provide us such service, this kind of systems need to adapt themselves automatically in response to the dynamic change of context. One of the greatest challenges of pervasive computing is to model context information due to the diversity of context information sources. Conciquantly, ther is an increasing need to construct a uniform context model that allows representing and reasoning upon useful contextual information. This paper presents a scalable ontology and rules-based model for representing and reasoning not only upon patient's health measurements which can be gathered from different Bio-Sensors, but also for reasoning on all useful contextual information that must be taken into consideration for providing the appropriate healthcare and smart home services. In future work, we plan to integrate our ontology in a real context-aware system that provides different services in pervasive healthcare environment in order to evaluate this ontology with different and heterogeneous entities such as bio-sensors and environmental sensors.

References

1. Catarinucci, L., Colella, R., Esposito, A., Tarricone, L., Zappatore, M.: Rfid sensor-tags feeding a context-aware rule-based healthcare monitoring system. Journal of Medical Systems, 3435–3449 (2012)
2. Fensel, D.: Ontologies: A silver bullet for knowledge management and electronic commerce, Berlin (2001)
3. Henricksen, K., Indulska, J., Rakotonirainy, A.: Modeling context information in pervasive computing systems. In: Mattern, F., Naghshineh, M. (eds.) PERVASIVE 2002. LNCS, vol. 2414, pp. 167–180. Springer, Heidelberg (2002)
4. Horrocks, I., Patel-Schneider, P.F., Boley, H., Tabet, S., Grosof, B., Dean, M.: Swrl: A semantic web rule language combining owl and ruleml. W3C Member Submission (2004)
5. Kim, J., Chung, K.: Ontology-based healthcare context information model to implement ubiquitous environment. Springer US (2011)
6. Ko, E.J., Lee, H.J., Lee, J.W.: Ontology-based context-aware service engine for u-healthcare. In: The 8th International Conference on Advanced Communication Technology, ICACT 2006, vol. 1, pp. 632–637 (2006)
7. Smith, M., Welty, C., McGuinness, D.: Owl web ontology language guide, `http://www.w3.org/TR/owl-guide/` (last access: February 2014)
8. Strang, T., Linnhoff-Popien, C.: A context modeling survey. In: The Sixth International Conference on Ubiquitous Computing, England (2004)
9. Thomas, J.: Protégé, `http://protegewiki.stanford.edu/wiki/Main_Page` (last access: February 2014)
10. W3C: Inference, `http://www.w3.org/standards/semanticweb/inference` (last access: February 2014)
11. W3C: Pellet, `http://www.w3.org/2001/sw/wiki/Pellet` (last access: February 2014)
12. Weiser, M.: The computer of the twenty-first century. Scientific American, 94–100 (1991)
13. Zeshan, F., Mohamad, R.: Medical ontology in the dynamic healthcare environment. Elsevier Ltd. (2012)