Towards Knowledge Oriented Personal Health Systems

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Abstract. Although current e-health tools such as personal health records have proven to be useful they still have many shortages. Especially, they do not provide effective means for querying personal health information. They also fail in information therapy, i.e., in providing the right information to right people at right time. In addition, they are totally passive, although through automating the control of patients health information we could significantly and cost-effectively improve the quality of patient-centered healthcare. In this paper, we describe our designed a knowledge oriented active personal health system, which does not suffer from these shortcomings. Its key components are the personal health ontology and the alerts. Through the ontology we can provide data expressive queries and avoid the problem of limited information supply, and through the alerts we can provide active elements for controlling patient's health information. We present the ontology in a graphical form and in OWL, and give rules for transforming the ontology into relational model. We also present how the alerts can be implemented by the triggers supported by relational database systems.

Keywords: E-health tools, Patient-centered healthcare, Personal health records, Information therapy, Ontologies, OWL, RDF, SOA, Relational database system, triggers.

1 Introduction

Patient-centered healthcare is widely studied (e.g., in [1, 2, 3, 4]) emerging e-health model that contributes to preventive medical care. It optimizes the healthcare system to focus on patient experience and outcomes for better health and well-being [5]. A key point in patient-centered healthcare is that patients and their families have the ability to obtain and understand health information and services, and make appropriate health decisions [6]. This requires that patient's health information as well as other relevant medical information is presented in appropriate format according to individuals understanding and abilities.

Our argument is that current XML-based e-health tools developed for managing personal health information do not satisfy well enough the requirements of patient-centered healthcare but instead knowledge oriented technologies are required for controlling and representing personal health information. In particular, we have

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discovered that existing personal health records (PHRs) [7] and e-health tools suffer at least from the following three weaknesses.

First, XML-based PHRs' data is document-centric-data, i.e., they are collections of documents such as documents including lab tests, prescribed medications and illnesses. By contrast, PHR usage often is data centric, meaning that data should be extracted from various documents and then integrated according to certain criteria. For example, a patient may be interested to know the average blood pressure and/or blood sugar concentration (glucose level) during the time periods he or she was using a drug for blood pressure or the patient may be interested to know the cholesterol values when he or she was on a diet. Unfortunately the computation required by such queries is not provided by the query languages (e.g., XPath [8] and XQuery [9]) that are designed to address XML documents.

Second, current e-health tools suffer from limited information supply. Our argument is that personal health system should support information therapy (Ix) [10], information based medicine [11], and the management of user specific physical exercises, as they contain the information that patients need in making appropriate health decisions. This is important as many studies have indicated that most patients are not satisfied with the medical treatment information on the Web though many e-health tools provide links to materials or other websites that have information about patient's health conditions or medications [11, 12]. In particular, they have regarded many sites to be overly commercial, or they could not determine the source of the information [13].

Third, existing PHRs are passive in the sense that they do not contain any active elements. By an active element we refer to an expression or statement that is stored in PHR (or in any e-health tool), and expect the element to execute at appropriate times. The times of action might be when a certain event occurs such as an insertion of a blood test result. Then depending on the inserted values an action can be taken such as generating an email to patient's personal physician.

In this paper, we describe our work on developing a knowledge oriented personal health system, which does not suffer from these three shortages. Its key components are the *personal health ontology* and the *alerts*. Through the ontology we can provide data centric queries and automate information therapy, and through the alerts we can configure appropriate active elements for each patient. Further, as a result capturing the features of many e-health tools in one system, a user does not have to use a variety of e-heath tools (which usually have their own heterogeneous interfaces) but all their functionalities can be captured into one system. In addition, through the shared ontology we can achieve synergy in developing more sophisticated services for the patient as well as we can avoid the problems of replicated data.

The rest of the paper is organized as follows. First, in Section 2, we describe the personal health ontology. Firstly, we characterize the nature of ontologies and represent the core components of the personal health ontology in a graphical form. Then we present the personal health ontology in OWL, and give examples of querying the ontology by RQL query language. In Section 3, we present the architecture of our developed personal health system. In particular, we describe how the personal health ontology can be transformed in the relational model, and how the alerts can be implemented by the triggers that are supported by relational database systems. Finally, Section 5 concludes the paper by discussing the advantages and limitations of our developed solutions.

2 Personal Health Ontology

Originally ontology is the philosophical study of the nature of being, existence or reality in general, as well as of the basic categories of being and their relations [14]. In the context of computer science, an ontology is a general vocabulary of a certain domain, and it can be defined as “an explicit specification of a conceptualization” [15]. It tries to characterize that meaning in terms of concepts and their relationships. It is typically represented as classes, properties, attributes and values. As an example consider a subset of the personal health ontology presented in Fig. 1.

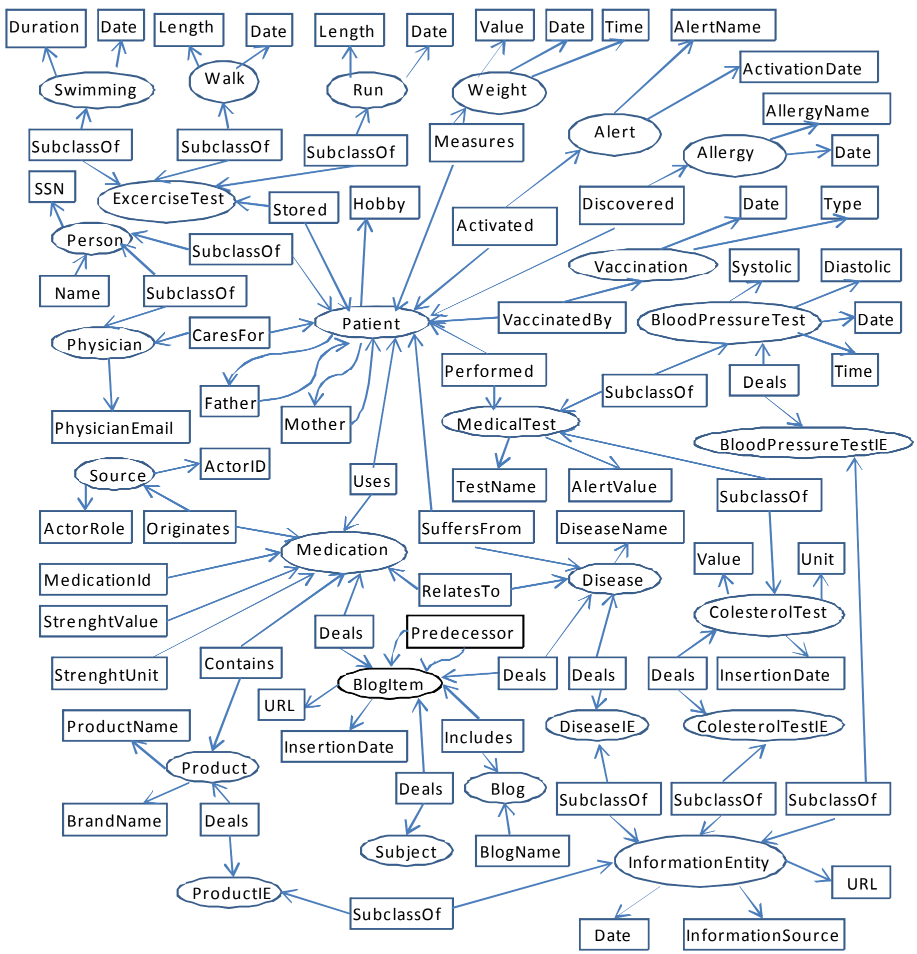

Fig. 1. A subset of the personal health ontology in a graphical form

In this graphical representation ellipses represent classes and subclasses, and rectangles represent data type and object properties. Classes, subclasses, data properties and object properties are modeling primitives in OWL (Web Ontology Language) [16]. Object properties (e.g., SuffersFrom) relate objects to other objects while data type properties (e.g., Hobby) relate objects to datatype values. In Fig. 1 we have presented only a few of objects' datatype properties.

The personal health ontology comprises the vocabulary that the patient can use in describing his or her personal health information. For example object properties Father and Mother are included in the vocabulary, but the patient does not have to give values for these properties. Note also that the datatype property Activated connects classes Patient and Alert. By giving the values for the datatype properties of the class Alert the patient indicates, which alerts he or she is activated. As we will see in the next section, active elements query these values and function accordingly.

A subset of the graphical ontology of Fig. 1 is presented in OWL in Fig. 2.

```
<rdf:RDF
        xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-nsl#"
        xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
        xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
        xmlns:owl="http://www.w3.org/2002/07/owl#">

        <owl:Ontology rdf:about=""PersonalHealthOntology"/>
         <owl:Class rdf:ID="Person/">
         <owl:Class rdf:ID="Medication/">
        <owl:Class rdf:ID="Disease/">
        <owl:Class rdf:ID="Patient/">
        <rdfs:subClassOf rdf:resource="#Person"/>
        </owl:Class>

        <owl:DatatypeProperty rdf:ID="Hobby">
                    <rdfs:domain rdf:resource="#Patient"/>
                    <rdfs:range rdf:resource="&xsd;string"/>
        </owl:DatatypeProperty>

        <owl:DatatypeProperty rdf:ID="ISSN">
                    <rdfs:domain rdf:resource="#Person"/>
                    <rdfs:range rdf:resource="&xsd;string"/>
        </owl:DatatypeProperty>

        <owl:ObjectProperty rdf:ID="Uses>
                    <rdfs:domain rdf:resource="#Patient/">
                    <rdfs:range rdf:resource="#Medication/>
        </owl:ObjectProperty>

        <owl:ObjectProperty rdf:ID="Suffers">
                    <rdfs:domain rdf:resource="#Patient/>
                    <rdfs:range rdf:resource="#Disease"/>
        </owl:ObjectProperty>
                    .
                    .
                    .
</rdf:RDF>
```

Fig. 2. A subset of the personal health ontology in OWL

As can be seen from Fig. 2, OWL ontologies are written using an RDF/XML syntax [17], i.e., they are RDF-elements. RDF itself is a data model. Its modeling primitive is an object-property-value triple, which is called a statement. For example, “Elisa Smith suffers from Diabetes” is an RDF-statement. RDF-statements are usually coded by XML, and so RDF is an XML-application [18].

As OWL ontologies are written by RDF, we can query the personal health ontology by query languages developed for RDF, e.g., by RQL [19] or SPARQL [20], which is standardized by the RDF Data Access Working Group (DAWG) of the World Wide Web Consortium, and is considered a component of the semantic web. On January 2008, SPARQL became an official W3C Recommendation.

Representing queries by RQL and SPARQL is easy for those who are familiar with database query languages. For example in RQL to retrieve all the information entities that deals cholesterol tests we only have to write “ColesterolTesrIE”. To retrieve the diseases that the patient, whose SSN is AB1234, suffers from, we have to write the RQL query presented in Fig. 3:

```
select N
from Disease{X} . SuffersFrom{Y}, {C}SSN{N}
where Y= “AB123” and X=C
```

Fig. 3. An RQL query on the personal health ontology

Note that in the context of traditional XML based PHRs (i.e., PHRs, which are not based on ontology but rather on an XML Schema developed from CCR [21] or CCD [22] standards), we can also request patients’ diseases. In contrast, as an example of a query that cannot be processed by query languages that address XML documents, consider the query:

“Give me the information entities that deal the diseases that I suffer from”.

The reason for this is the fact that behind XML-documents there is only an XML-schema, which only specifies the syntactical structure of the document but says nothing about the relationships of the elements such as “information entity” and disease”. However, this kind of queries can be answered based on the personal health ontology as it connects patients to diseases and diseases to information entities. This query also illustrates the synergy that we can achieve in capturing personal health information and information entities in the same ontology. In addition, it enables the automation of information therapy. That is, we can specify an active element, which is executed when a new disease for a patient is inserted in the ontology, and then the above query is executed and its result is delivered to the patient.

3 Implementing the Personal Health System

The data of the personal health ontology is received and gathered up from a variety of health care organizations. However before the data can be inserted in to the ontology it must be transformed into RDF-format that is compatible with the personal health ontology. As illustrated in Fig. 4 such transformations require that a specific stylesheet [14] is developed for each data source. Transformed data is then delivered through the SOAP-protocol [23] to the personal health system, which inserts the data into the knowledge base.

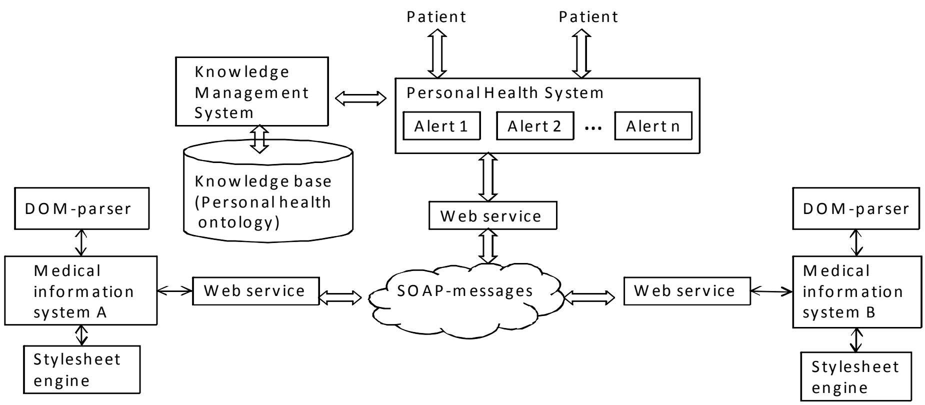

Fig. 4. The architecture of the communicating software modules

As our developed personal health ontology does not (so far) include any inference rules we do not need a specific semantic reasoner [14], such as Jena, FaCT or OWLIM, for managing the ontology. Instead we use a relational database management system (Oracle) [24] for storing the ontology.

A gain of using relational database system is that we can easily implement the alerts by exploiting triggers that are supported by relational systems. A *trigger* is a procedure that is automatically invoked by the database system in response to specified changes to the database. These procedures are stored in the database (thereby also called stored procedures). Otherwise, if we would not use relational database system we would have to store the code of the alerts into personal health system. Fig. 4 illustrates such a case. However, as our current version exploits relational system we next describe its implementation.

Especially we have transformed the personal health ontology (i.e., an OWL ontology) into a relational schema, which specifies the logical structure of the database. The *schema* specifies the names of the relations, their attributes, key constraints and constraints in general.

We have used the following rules in the transformation:

- The name of the OWL class and subclass is the name of the relation.
- Each data and object property of the OWL class (and its superclass if any) is an attribute of the relation.
- The key of the relation is comprised of the identification of the OWL class and of the identification of those OWL classes that are in a multivalued relationship to the OWL class.

Before considering produced relation schemas we specify triggers. A *trigger specification* [24] contains the following three parts:

- Event: A change to the database that activates the trigger.
- Condition: A query or test that is run when the trigger is activated.
- Action: A procedure that is executed when the trigger is activated and its condition is true.

In order to illustrate the deployment of triggers let us consider the following two relation schemas that are resulted from translating the OWL ontology int relation schemas, and then normalized into Boice-Codd Normal Form [24] (normalization is required in order to avoid the existence of redundant data in the database, which may give rise for a variety of anomalies).

PatientDiseases (SSN, DiseaseName), PatientAlerts (SSN, AlertName)

The former indicates patient's diseases while the latter specifies the alerts that the patients has activated. For illustrative purposes we define the trigger InformationEntityAlert in informal way. This trigger can be used to automate information therapy, i.e., when a new disease is inserted into patient's personal health ontology, then the information entities dealing the disease are delivered to the patient.

Trigger name: InformationEntityAlert
Event: On Insertion on relation PatientDiseases.
Condition: Whether patient has activated Information entity alert (i.e., whether the tuple <"PatientSSN", InformationEntityAlert> is in the relation PatientAlerts).
Action: The stored procedure is executed, which requests from the database which information entities deal the inserted disease, and delivers the result to the patient (e.g., by an email).

4 Conclusions

"Patient-centered healthcare" is the term that is used to describe healthcare that is designed and practiced with the patient at the centre. It subscribes to the belief that the patient has strengths, values and experiences that are important in the healthcare experience and relationship between those providing care and the patient. It is based on the assumption that physicians, patients and their families have the ability to obtain and understand health information and services, and make appropriate health decisions. This in turn requires health information should be presented according to individuals understanding and abilities.

Although current e-health tools such as personal health records have proven to be useful in patient-centered healthcare they still have many shortages. Especially, they do not provide effective means for querying personal health information. They also fail in providing relevant information to patient at right time. In addition they are totally passive, although through automating the control of patients health information we could cost-effectively improve the quality of patient-centered healthcare.

However, as we have described, by integrating the functionalities of various e-heath tools and by providing active elements, we can achieve many improvements in patient-centered health care.

An important requirement in introducing our developed solutions is that the sources of the data that are stored in the personal health ontology transform the delivered data in the format that is consistent with the personal health ontology. This is the extra work required from the health care organizations producing data into the personal health ontology.

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