MOVING FROM REMOTE PATIENT MONITORS TO CLOUD-BASED PERSONAL HEALTH INFORMATION SYSTEMS

A Way to Practicing Patient-centered Chronic Care Model

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Abstract: Recent advances in remote patient monitoring allow patient to transmit vital health data from their home to physicians' offices and receive health coaching from their healthcare providers based on the clinical data they have sent. Unfortunately such a remote monitoring technology only provides the connection between patients and healthcare providers and thus does not support new emerging healthcare models such as patient-centered care, pharmaceutical care or chronic care models. These healthcare models need technology solutions that (i) support the co-operation within patient's healthcare team (i.e., connect patients, patient's family members and healthcare professionals), (ii) provide a platform for sharing patient's healthcare data among the healthcare team, and (iii) provide a mechanism for disseminating relevant educational material for the patient and the healthcare team. In this paper, we describe our work on designing a personal health information system, which supports patient remote monitoring and the new emerging healthcare models as well. The key idea is to develop the system by integrating relevant e-health tools through a shared ontology and to exploit the flexibility of cloud computing in its implementation. In developing the ontology we have used semantic web technologies such as OWL and RDF.

1 INTRODUCTION

The introduction of new emerging healthcare models, such as patient-centered care, pharmaceutical care, and chronic care model, are changing how people think about health and of patients themselves.

Patient-centered care (Bauman et al., 2003; Gillespie et al., 2004; Little et al., 2001) emphasizes the coordination and integration of care, and the use of appropriate information, communication, and education technologies in connecting patients, caregivers, physicians, nurses, and others into a healthcare team where health system supports and encourages cooperation among team members. 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 (Michie et al., 2003). This in turn requires that health information should be presented according to individuals understanding and abilities (Stewart, 2004).

Pharmaceutical care emphasizes the movement of pharmacy practice away from its original role on drug supply towards a more inclusive focus on patient care (Wiedenmayer et al., 2006; Mil et al., 2004; Hepler and Strand, 1990). It emphasizes the responsible provision of drug therapy for the purpose of achieving definite outcomes that improve patient's quality of life (WHO, 1997; Hepler, 2004).

Chronic care model (Fiandt, 2011; Boult et al, 2008) emphasizes patients' long-term healthcare needs as a counterweight to the attention typically paid to acute short-term, and emergency care. In this sense, the traditional care models are not appropriate as the patients with chronic illness do not receive enough information about their condition, and they are not supported in caring themselves after they leave the doctor's office or hospital.

Patient remote monitoring and home telehealth technologies provide a variety of tools for patients to

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take an active role in the management of their chronic diseases. Especially, the ability to monitor and interact with patient from a distance by exploiting electronic devices to record and send the measurements of patients' vital signs to a caregiver has been a key technology in fostering patients' ability to receive care at home**.** Earlier the only reliable means of controlling such measurements has been for a medical professional to take them directly, or for a patient to be constantly monitored in hospital, which would normally only happen once the patient has become seriously ill.

The new technologies and principle of practicing medicine holds significant promise of improving on major health care delivery problems. However, there are many functions in the patient-centered care, pharmaceutical care and chronic care models that the home telehealth devices and the e-heath tools such as personal health records do not support.

For example, patients that are out of hospital or who are left hospital often have concerns about their medicines, and so there is strong demand for extending the functionalities of home telehealth devices by the functions of pharmaceutical care. Neither the current e-heath tools support the coordination of the care, nor the social connections among the members of patient's healthcare team. They also fail in providing comprehensive access to patient's health data and in promoting patient's medical education.

Inspired by the (semantic) web technologies and the flexibility of cloud computing, we have studied their suitability for supporting the emerging healthcare models. Our studies have indicated that Personal Health Information Systems (PHIS) should support the functionalities of many traditional e-health tools such as remote patient monitors, personal health records, health-oriented blogs, and health-oriented information servers. It is also turned out that by gathering these functionalities into one system we can achieve synergy, i.e., achieve functionalities that would not be obtainable by any of the e-health tools independently.

In gathering the functionalities we have adapted the ideas of knowledge centric organizations to PHIS, i.e., we have revolved the e-health tools around a health oriented knowledge base. So, all the e-heath tools share patient's health data. Further by exploiting the characteristics provided by cloud computing we can easily ensure the interoperation of patient's healthcare team: accessing the PHIS requires only internet connection. Instead of the prevailing systems provided by healthcare organizations do not provide appropriate technology for co-operation as their use is devoted to organization's healthcare personnel only.

The rest of the paper is organized as follows. First, in Section 2, we motivate our work by considering the recent advances in patient remote monitoring. Then, in Section 3, we present the requirements of PHIS that we have derived from emerging healthcare models, and then, in Section 4, we analyze the suitability of cloud computing for satisfying these requirements. In Section 5, we present the architecture of the knowledge oriented PHIS and the PHIS-ontology that is shared by the e-health tools. In Section 6 we describe how the PHIS-ontology can be exploited in promoting patient's medical education and in delivering relevant information within patient's healthcare team. In Section 7, we illustrate how XSLT-transformations is used in transforming XML-coded medical data in the format that is compliant with the PHIS-ontology. Finally Section 8 concludes the paper by discussing the challenges of our solutions as well as our future research.

2 REMOTE PATIENT MONITORING

Telemedicine is the use of medical information exchanged from one site to another via communications to improve a patient's health (Angaran, 1999; Kontaxakis et al., 1990). Telemedicine is viewed as a cost-effective alternative to the more traditional face-to-face way of providing medical care (Kontaxakis, 2006).

Telemedicine can be broken into three main categories: store-and-forward, interactive services and remote patient monitoring.

- *Store-and-forward telemedicine* involves acquiring medical data and then transmitting this data to the system that is accessible to patient's physician. So it does not require the presence of patient and physician at the same time.
- *Interactive services* provide real-time interactions between patient and physician. It includes phone conversations, online communication and home visits.
- *Remote monitoring* enables medical professionals to monitor a patient remotely using various technological devices. Remote monitoring is above all used for managing chronic diseases such as heart disease, diabetes and asthma.

Nowadays remote patient monitoring technologies are becoming a more sophisticated, integrated, and systematic approach to healthcare that can be personalized to each patient's medical needs. In particular, Personal Health Systems (PHSs) go beyond the simple remote patient monitoring systems in that they enable the communication between patients and healthcare professionals and provide clinicians with access to current patient data. They also provide interactive tools for personalized care management including vital sign collection, patient reminders and communication tools such as video conferencing capabilities, allowing remotely located health care professionals to interview, observe and educate the patient, as well as assist in the use of the peripherals or other medical devices. Some devices also have the ability to show video, which can be used for educating the patient.

From technology point of view personal health systems consist of a hub and wireless peripheral devices that collects physiologic data. Typical peripheral devices include blood pressure cuffs, pulse oximeters, weight scales blood glucose meter. The data gathered from peripheral devices are transmitted by the hub to a clinical database for later analysis (Figure 1).

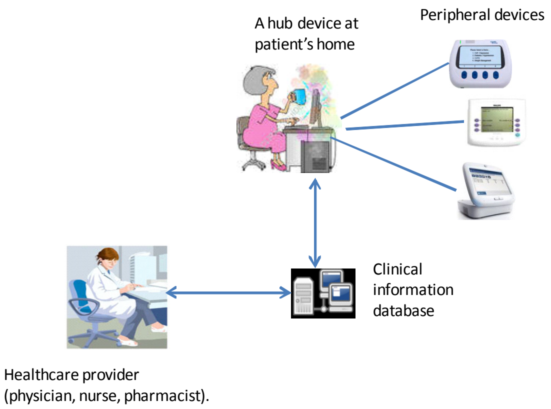

Figure 1: Remote monitoring through a clinical information database.

3 INFORMATION FLOWS IN PHIS

The technology that supports both patient centered healthcare and pharmaceutical care of the patients with chronic conditions have to coordinate the flows of information that are coming from a variety of sources. These information flows include:

- Vital sign information from peripheral devices (that collect physiologic data) to PHIS.
- Health regimen information between healthcare providers (physicians, nurses and pharmacists).
- Information between patient and healthcare providers.
- Healthcare information between healthcare providers and patient's family members.
- Relevant educational health information from healthcare providers to patient.

Supporting these information flows is much more challenging as the simple vital sign information flow that characterized an earlier generation of remote patient monitoring. In particular the traditional remote monitoring model (illustrated in Figure 1) supports only partially these requirements as the usage of the clinical information system is isolated from third parties such as from patient's family members.

Apart from the co-operation support, the member's of patient's healthcare team should have a seamless access to patient's health data, which is usually stored in electronic health record (EHR) (EHR, 2011) or personal health records (PHR) (Raisinghani and Young, 2008). The former is managed by medical authorities while the latter managed by the patient and all that are authorized by the patient are allowed to access it (Puustjärvi and Puustjärvi, 2011). Hence patient's PHR, which in our architecture is a component of the PHIS, has a central role to support emerging healthcare models.

4 CLOUD-BASED PHIS

Cloud computing is a technology that uses the Internet and central remote servers to maintain data and applications (Chappel, 2011). It is an evaluation of the widespread adoption of virtualization, service oriented architecture and utility computing (Wikipedia, 2011). The name cloud computing was originally inspired by the cloud symbol that's often used to represent the internet in diagrams.

Cloud computing allows consumers and businesses to use applications without installation, and they can access their personal files at any computer with internet access. This technology allows for more efficient computing by centralizing storage, memory, processing and bandwidth. Further, unlike traditional hosting it provides the following useful characteristics:

- The resources of the cloud can be used on demand, typically by the minutes.

- The used resources are easily scalable in the sense that users can have as much or as little of a service as they want at any given time.
- The resources are fully managed by the provider. The consumer does not need any complex resource, only a personal computer with internet access.

Software as a service (SaaS), is a type of cloud computing. In this service model, a service provider licenses an application to customers either as a service on demand, through a subscription, in a "pay-as-you-go" model, or at no charge (Khajeh-Hosseini, 2011). The SaaS model to application delivery is part of the utility computing model where all of the technology is in the "cloud" accessed over the internet as a service.

There are various architectural ways for implementing the SaaS model including the followings (Chappel, 2011):

- Each customer has a customized version of the hosted application that runs as its own instance on the host's servers.
- Many customers use separate instances of the same application code.
- A single program instance serves all customers.

In the case of PHISs the required computation is rather small compared to traditional business applications and thus the last mentioned architecture is appropriate for the implementation of the PHIS, i.e., a single PHIS serves all patients. However, patient specific data can only be accessed by the patient and those that are authorized by the patient. The SaaS-based PHIS and its users are presented in Figure 2.

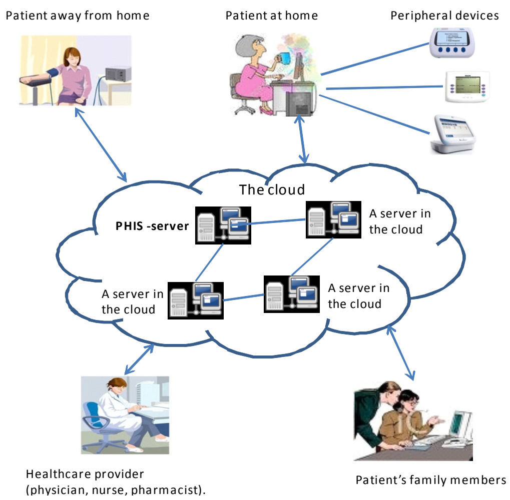

Figure 2: The users of the cloud-based PHIS.

We next itemize some clarifying aspects of the figure:

- The cloud takes the advantages of SOA (Service Oriented Architecture) in the interoperation of the services, e.g., in importing patient's health data the PHIS-server interoperates with the servers of other healthcare organizations including hospitals, physicians' offices and health centers.
- As the figure illustrates the peripheral devices that the patient has at home are connected to patient's PC, and so the vital signs collected by the devices are transmitted via the PC to the cloud, i.e., to the PHIS.
- The patient accesses his or her health data stored in PHIS through the browser. As the patient needs nothing but an internet access, the patient can easily connect to the PHIS at home, as well as being away from home.
- Healthcare providers and patient's family members that are authorized by the patient can access patient's health data as well as communicate through their browsers.

Next, we consider the internal structure of the PHIS-server.

5 PHIS-ONTOLOGY

The architecture of the PHIS and its connections in the cloud are presented in Figure 3. As the figure illustrates patient and the members of his or her healthcare team access the PHIS-server through the personalized health portal. It is a site on WWW that provides personalized capabilities for its users and links to other relevant servers.

In designing the PHIS we have followed the idea of knowledge oriented organizations (Daconta et al., 2003), where the key idea is to revolve all applications around a shared ontology (stored in a knowledge base), which we call *PHIS-ontology*. It is developed by integrating the ontologies of the e-health tools supported by the PHIS. For now we have integrated the ontologies of the Blog manager, Information therapy (Ix) manager, Remote manager, and PHR manager. Such an internal architecture of the PHIS is presented in Figure 4.

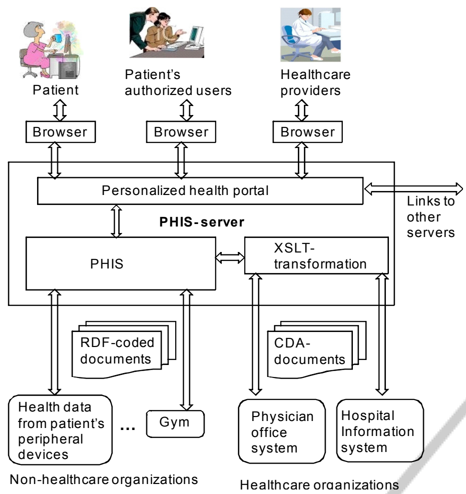

Figure 3: The component of the PHIS-server and its external connections.

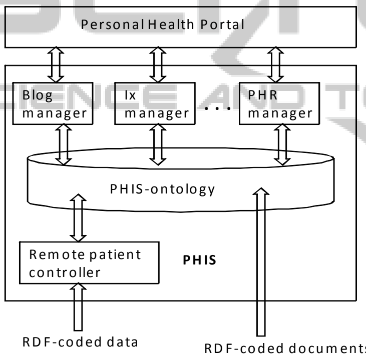

Figure 4: The e-heath tools accessing the PHIS-ontology.

Figure 5 illustrates the idea of the knowledge base and the case where PHIS-ontology is developed by integrating the Blog-ontology, Ix-ontology, PHR-ontology and RM-ontology (Remote Monitoring ontology). In the figure ellipses represent OWL´s classes, rectangles represent OWL's data properties and the lines between ellipses represent OWL's object properties. Accordingly class A is shared by all the four ontologies.

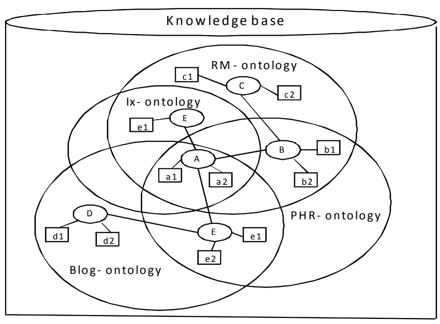

Figure 5: PHIS-ontology.

In order to illustrate shared classes, A could be class *Disease*, *B* class *Patient*, and *C* class *Informal_entity*. Further assume that object property A-B is *suffer_from*, object property *A-E* is *deals*, data property *b1* is *patient_name*, and data property *e1* is a *url*. In such as setting we could specify by RDF (Resource Description Framework) that John Smith suffers from diabetes and the educational material dealing diabetes is stored in a specific url.

A portion of the PHIS-ontology is graphically presented in Figure 6. In this graphical representation ellipses represent classes and subclasses, and rectangles represent data and object properties.

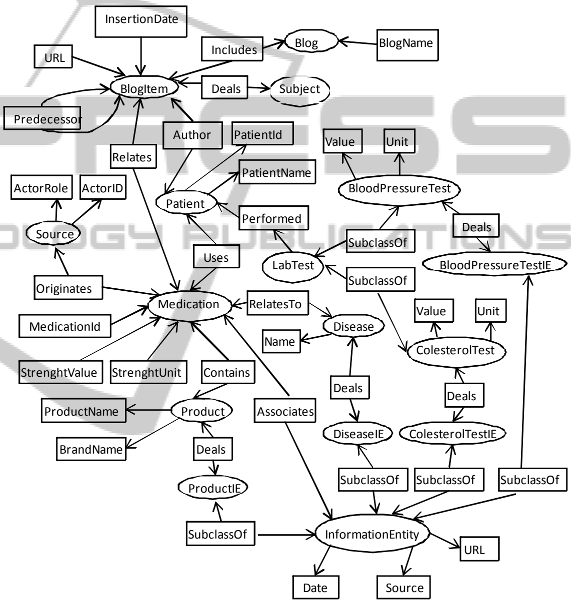

Figure 6: A portion of the PHIS-ontology.

A portion of the graphical ontology of Figure 6 is presented in OWL in Figure 7.

In order to understand the relationship of XML, OWL and RDF note that XML (Extensible Mark-up Language) (Harold and Scott, 2002) is just a meta language for defining markup languages. By a meta language we refer to a language used to make statements about statements in another language, which is called the object language. Accordingly RDF (RDF, 2011) and OWL (OWL, 2011) are object languages. Instead, XML says nothing about the semantics of the used tags. It just provides a means for structuring documents. Due to the lack of semantics we do not use XML for representing PHIS-ontology but instead we use ontology languages RDF and OWL.

```
<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:owl=http://www.w3.org/2002/07/owl#>

        <owl:Ontology rdf:about=“”PHA/>
         <owl:Class rdf:ID=“Blog/”>
         <owl:Class rdf:ID=“BlogItem/”>
        <owl:Class rdf:ID=“Patient/”>
        <owl:Class rdf:ID=“Medication/”>
        <owl:Class rdf:ID=“Source/”>
        <owl:Class rdf:ID=“Product/”>
        <owl:Class rdf:ID=“LabTest/”>
        <owl:Class rdf:ID=“BloodPressureTest”>
                <rdfs:subClassOf rdf:resource=“#LabTest”/>
        </owl:Class>
        <owl:Class rdf:ID=“ColesterolTest”>
                <rdfs:subClassOf rdf:resource=“#LabTest”/>
        </owl:Class>

        <owl:ObjectProperty rdf:ID=“Relates”>
                <rdfs:domain rdf:resource=“#BlogItem”/>
                <rdfs:range rdf:resource=“#Medication”/>
        </owl:ObjectProperty>

        <owl:ObjectProperty rdf:ID=“Uses”>
                <rdfs:domain rdf:resource=“#Patient”/>
                <rdfs:range rdf:resource=“#Medication”/>
        </owl:ObjectProperty>
                .
                .
                .
</rdf:RDF>
```

Figure 7: A portion of the PHIS-ontology in OWL.

6 PROVIDING INFORMATION FLOWS AND MEDICAL EDUCATION

As we have already stated the technology that supports emerging healthcare models should coordinate the flows of information within patient's healthcare team as well as provide educational relevant material. In our developed solutions these functionalities are carried out by the information stored in the PHIS –ontology. In particular these functionalities exploit the instances of the classes *BlogItem* and *InformationEntity*.

Each instance of the class *BlogItem* represents an entry in patient blog. By its object property *Predecessor* the entries are presented in chronological order with the latest entry listed first, and by using the object property *Deals* blog's entries can be classified into different subjects. Patient and patient's healthcare team are allowed to access and create new entries for the blog through the functionalities provided by the Blog manager.

Each instance of the class *InformationEntity* represents an educational material. Its data property *url* specifies the location of the actual content of the material, i.e., the instance. As illustrated in Figure 6, the PHIS-ontology also specifies the relationships of the class *InformationEntity* to other relevant classes such as *Medication* and *Disease*. Thus, based on these relationships relevant educational material can be automatically delivered to the patient. For example, we can query the information entities that deal the diseases that patient John Smith suffers from. Further, by activating such queries (by the Ix-manager) when new disease is inserted for a patient, we can automate information therapy, i.e., prescribe the right information to right patient at right time.

7 TRANSFORMING XML-CODED DOCUMENTS

As we have already illustrated in Figure 3, the PHIS-server does not only import data from patients home telehealth devices but it also imports data from other information sources such as a hospital laboratory, gym and physician office.

If the format of the imported data does not coincide with the PHIS-ontology, then the stylesheet engine (Daconta, et al., 2003) is required for transforming the imported data before its insertion into the PHIS-ontology. Such a transformation is illustrated in Figure 8.

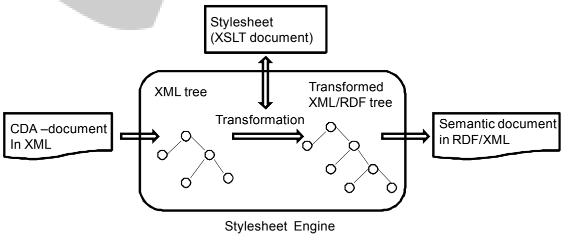

Figure 8: Transforming CDA-documents into semantic documents.

CDA-documents are typical XML-based documents, and so they are not compliant with the PHIS-ontology. By the CDA-documents we refer to documents that are based on the Clinical Document Architecture (CDA), which is an ANSI approved HL7 standard (Dolin et al., 2001). It is proven to be a valuable and powerful standard for a structured exchange of persistent clinical documents between different software systems (Puustjärvi and Puustjärvi, 2009).

However, in the case of non persistent documents with CDA we encounter many problems. The main reason for this is that the semantics of the CDA-documents is bound to the shared HL7 Reference Information Model (RIM) (Dolin et al., 2001). Thereby introducing new document types would require to extending the RIM, which is a long lasting standardization process. So this approach contradicts with our requirement of flexibility in introducing new document types in importing health information into the PHIS-ontology. Therefore in importing data from XML-based data sources (e.g., from HL7 CDA compliant systems) requires that the XML-formatted data is first translated (by an XSLT-based style sheet engine (Harold and Scott, 2002) into RDF and then inserted into the PHIS-ontology.

In order to illustrate this transformation consider the CDA document of Figure 9.

```
<ContinityOfCareRecord>
   <Patient>
      <ActorID>AB-12345></ActorID>
      <ActorName> Susan Taylor</ActorName>
   </Patient>
   <Medications>
     <Medication>
       <Source>
          <ActorID>Pharmacy of Kaivopuisto</ActorID>
          <ActorRole>Pharmacy</ActorRole>
       </Source>
       <Description>
          <Text>One tablet ones a day</Text>
          <GenericSubstitutionInfo>
              http://www.../medicalinfo/SubstitutionInfo
             </GenericSubstitutionInfo>
        </Description>
        <Product>
             <ProductName>Valsartan</ProductName>
                  <ProductInfo>
                     http://www.../medicalinfo/ValsartanInfo
                </ProductInfo>
        </Product>
        <Strenght>
           <Value>50</Value>
            <Unit>milligram</Unit>
        </Strenght>
        <Quantity>
            <Value>30</Value><Unit>Tabs</Unit>
         </Quantity>
   </Medication>
  </Medications>
</ContinityOfCareRecord>
```

Figure 9: A CCR document.

Figure 9 represents a CCR file that has a medication list (element Medications), which is comprised of one medication (element Medication) that is source stamped by the Pharmacy of Kaivopuisto. The CCR file is based on the CCR standard (CCR, 2011).

The CCR standard as well as the CCD standard (HL7, 2011) are originally a patient health summary standards, and later on these standards are commonly exploited in structuring the data in personal health records. From technology point of view these standards represent two different XML schemas designed to store patient clinical summaries (Puustjärvi and Puustjärvi 2009). However, both schemas are identical in their scope in the sense that they contain the same data elements.

After the XSLT transformation the CCR document of Figure 9 is in the RDF/XML format presented in Figure 10. In this format the document is compliant with PHIS-ontology and can be inserted into the PHIS-ontology.

```
<rdf:RDF
  xmlns : rdf=http://www.w3.org/1999/02/22-rdf-syntax-ns#
  xmlns : po=http://www.lut.fi/ontologies/PHIS-ontology#>
  <rdf:Description rdf:about=”AB-12345”>
        <rdf:type rdf:resource=“&po;Patient”/>
        <po : PatientName>Susan Taylor</po:PatientName>
        <po:Uses rdf:resource=“&po;Med-07092010”/>
   </rdf : Description>
   <rdf:Description rdf:about=” Med-07092010”>
                    <rdf:type rdf:resource=“&po;Medication”/>
        <po:Contains rdf:resource=“&po;Valsartan”/>
                     <po : StrenghtValue rdf:datatype=
                          ”&xsd;integer”>30</po : StrenghtValue>
                     <po : StrenghtUnit>Tabs</po : StrenghtUnit>
    </rdf : Description>
    <rdf:Description rdf:about=”Valsartan”>
                     <rdf:type rdf:resource=“&po;Product”/>
         <po:Deals rdf:resource=“&info;ValsartanInfo”/>
    </rdf : Description>
    < rdf:Description rdf:about=” Pharmacy of Kaivopuisto”>
                     <rdf:type rdf:resource=“&po;Source/>
                     <po: ActorRole>Pharmacy</po : ActorRole>
     </rdf : Description>
</rdf:RDF>
```

Figure 10: Transformed CDA document in RDF/XML format.

The RDF/XML-formatted document of Figure 10 is comprised of four RDF-descriptions. Further, the first RDF-description is comprised of three RDF-statements. The first statement states that the type of the instance identified by “AB-12345” is Patient in the PHIS-ontology. The second RDF-statement states that the name of the instance identified by “AB-12345” is Susan Taylor.

8 CONCLUSIONS

Monitoring a patient’s vital signs provides an important source of information to the physician that treats the patient. Nowadays information and communication technology provides the possibility of a new generation of lightweight monitoring systems which a patient can wear while being at home or while going about their daily business. Formerly the only reliable means of such monitoring has been for a medical professional to take them directly, or for a patient to be constantly monitored in hospital.

The new patient remote monitoring technology holds significant promise of improving on major health care delivery problems. However, there are many functions in the emerging healthcare models (including patient centered care, pharmaceutical care and chronic care models) that the modern monitoring devices and systems do not support as they only provide the communication between patient and healthcare provider. Instead the emerging healthcare models require Information and Communication Technology (ICT) support for the co-operation of patient's healthcare team and the support in delivering relevant educational material for the patient and the members of the healthcare team.

Our studies have shown that the ICT-support of these requirements requires the integration of patient's e-health tools as it significantly simplifies patients' interaction with the services, enables the co-operation within the healthcare team and the development of new services such as automated information therapy.

From technology point of view we have integrated e-heath tools through the shared PHIS-ontology that is stored in the knowledge base, which exploits semantic web technologies such as OWL and RDF. The management of the shared ontology requires that in importing data the documents that are not compliant with the ontology have to be transformed by XSLT transformation into the RDF-format that is compliant with the ontology, i.e., a stylesheet has to be defined for each non-compliant document type.

In our future work we will study the effects of introducing cloud-based health information systems on the mind-set of patient and healthcare personnel as the introduction of these technologies also changes the daily duties of the patient and many healthcare employees. Therefore we assume the most challenging aspect will not be the technology but rather the changing the mind-set of patient's healthcare team.

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