The Challenges of Electronic Prescription Systems Based on Semantic Web Technologies

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Abstract: The technology developed for interoperable autonomous systems has significantly changed during the past few years. However, this new technology based on Semantic Web is not yet deployed in electronic prescriptions systems. On the other hand, during the past few years several organizations in the healthcare sector have produced standards and representation forms using XML. This generalization of XML-technologies sets a promising starting point for the interoperability of the various organizations in the healthcare sector. However, the introduction of XML is not enough but many other XML-based technologies have to be introduced in order to achieve a seamless interoperability between the electronic prescription systems and other organizations of the health care sector. In this article we illustrate the querying facilities that the deployment of the semantic web technology can provide for electronic prescriptions systems. Furthermore we illustrate the system architecture and the ontologies as well as the ontology specification languages that are required in implementing an electronic prescription system based on semantic web technologies.

1 Introduction

Imagine that you are on a vacation on the other side of the world, and you become suddenly ill and must be hospitalized. Immediately the physician in the hospital queries the Internet, entering your universal health identification number and within few seconds the physician access your complete medical history including your patient record, medical chart and blood analysis. Then the physician queries your previous prescriptions such as the amount of certain drugs, and your digital X-ray films. After this the physician constructs the prescription by the prescription writer which checks whether the drugs have mutual negative effects with your other ongoing medical treatment, and finally the appropriate treatment is provided.

Unfortunately this scenario is not possible today. Accessing your complete medical history or previous prescriptions through Internet is not possible. The main reasons for this are the isolation of various healthcare systems and the lack of standardization of medical data such as patient records and electronic prescriptions. By the standardization we refer to the medical ontologies that give semantics for medical data.

The academic research of electronic prescriptions is discussed in many practitioner reports and public national plans, e.g., in [Hy05, Bo05, CM04, SG00, Ke99, Ve06]. These plans share several similar motivations and reasons for the implementation of electronic prescription systems (EPSs). These include:

- Reduction of medication errors
- Speeding up the prescription ordering process
- Better statistical data for research purposes
- Financial savings

The technology developed for interoperable autonomous systems has significantly changed during the past few years. However the new technology based on Semantic Web [AH04, DO03, SH05] is not yet deployed in health care sector. Through this technology many of the features of the previous scenario could be achieved. On the other hand, during the past few years several organizations in the healthcare sector have produced standards and representation forms using XML. For example, patient records, blood analysis and electronic prescriptions are typically represented as XML-documents [Wo01, St01, Li01, Ju05, Ma05]. This generalization of XML-technologies sets a promising starting point for the interoperability of the various organizations in the healthcare sector. However, the introduction of XML [HS02] itself is not enough but also many other XML-based technologies [SH05] have to be introduced in order to achieve a seamless interoperability between the organizations within the healthcare sector.

In this article we illustrate the interoperability within the healthcare sector from electronic prescriptions point of view. In particular, we illustrate

- how XML-based technologies can be utilized in modeling the concepts that are related to prescription writing, and
- how web-service technology can be used in implementing the interoperability of electronic prescription system and other healthcare systems.

The main goal of this article is to show the gains that the integration of the health care systems and the deployment of the Semantic Web technologies can provide for electronic prescription systems.

The rest of the paper is organized as follows. First in Section 2, we give a motivation by illustrating an overview of a paper based prescribing system and electronic prescribing system. Especially we will illustrate the way the physician can utilize the new querying facilities the EPS (Electronic Prescription System) may provide. Then, in section 3, we describe our proposed service oriented architecture for EPS. An essential feature of the architecture is that the components interact through web service interfaces. In Section 4, we consider EPSs from conceptual modeling point of view. Especially we illustrate the role of XML-based technologies and the appropriate ontologies in the development of EPSs. Chapter 5 concludes the paper by discussing the advantages and disadvantages of our approach.

2 Motivation

We first shortly describe the process behind the paper-based prescription system. It goes as follows: first a patent visits a physician for consultation. After the consultation the physician writes a medical prescription of drugs for the patient on a paper prescription form. Then the physician signs this form by hand and gives the prescription form to the patient. The patient can then present the prescription form at any pharmacy in the country. Then, in a pharmacy, the pharmacist dispenses the prescribed drugs listed on the prescription to the patient and keeps the prescription form. The prescriptions dispensed by a pharmacy are periodically batched together and sent to a governmental authority which after processing the prescriptions sends payments to the pharmacy.

We next illustrate how the electronic prescription process may deviate from the paper-based prescription process. It goes as follows: first a patient visits a physician for diagnosis. In prescribing medication the physician uses the EPS. The EPS may provide for example the following queries

- querying the previous prescriptions of the patient,
- querying statistical information about previous prescriptions such as the amount of certain drugs,
- querying patients records,
- querying the physicians given previous prescriptions, or
- querying the digital X-ray films of the patient.

In addition, the physician may annotate the prescription by appropriate information, e.g., by stating that the drugs are not allowed to be given before certain date, and that the drugs are given in certain portions, e.g., a portion once a month. And, on the other way round, the physician may express queries on the annotations such as whether the drugs are previously given up in one or several portions.

Once the physician has constructed the prescription the EPS may automatically

- check in the case of multi drug treatment whether the drugs have mutual negative effects,
- check whether the drugs have mutual negative effects with the other ongoing medical treatment of the patient,
- check the dose,
- check whether some of drug can be changed to a cheaper drug.

Once the checks and possible changes have been done the physician signs the prescription electronically. Then the prescription is encrypted and sent to an electronic prescription holding store. Basically the holding store may be centralized or distributed store. The patient will also receive the prescription in the paper form, which includes two barcodes. The first identifies the address of the prescription in the holding store, and the second is the encryption key which allows the pharmacist to decrypt the prescription.

3 The architecture of the service oriented e-prescription system

We now describe the architecture that can be used for providing the services described in Section 2. The architecture is based on the service oriented computing paradigm. Basically, services are a means for building distributed applications more efficiently than with previous software approaches. The main idea behind services is that they are used for multiple purposes. Services are also used by putting them together or composing them. Therefore every aspect of services is designed to help them be composed.

In the health care sector service oriented computing provides an elegant approach for connecting electronic prescription system to the other relevant health care systems. For example, electronic prescription writer can interact with the health care system that supports patient records. There may also be components that are used by different healthcare systems. For example, medical database may provide services for medical information systems as well as for electronic prescription system.

The communication is based on the notion of web services [Ne02]. Originally they provide a way for executing business transactions in the Internet but they can be used in ehealth sector as well. Technically web services are self-describing modular applications that can be published, located and invoked across the Web. Once a service is deployed, other applications can invoke the deployed service. In general, a web service can be anything from a simple request to complicated business or ehealth processes.

The components of the electronic prescription system are presented in Figure 1. In reality, each component communicates through a web service interface, but in Figure 1 in order to keep the figure clear we have omitted those interfaces.

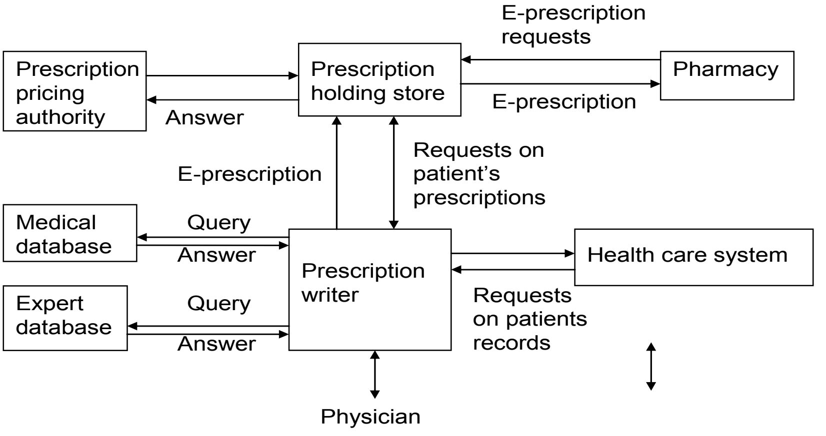

Figure 1. The components of an e-prescription system.

.In Figure 2, we have presented a more detail structure of the Prescription holding store which also includes the web service interface.

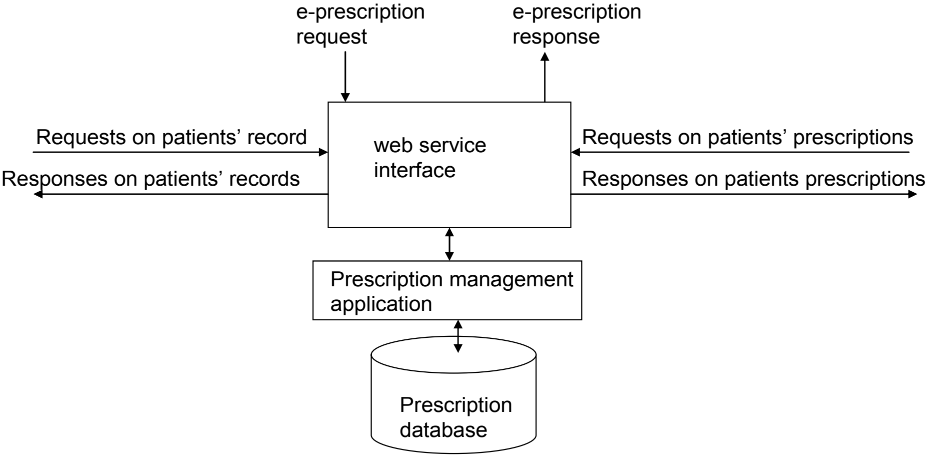

Figure 2. The components of the prescription holding store.

Note that each message in the Figure 2 is presented as an XML-document. Further, each XML-document is carried by the SOAP protocol [SH05]. SOAP is a protocol specification that defines a uniform way of passing XML-coded data.

4 Ontologies for electronic prescription systems

In this section we will first give a short introduction to ontologies. Then we illustrate what kind of ontology languages are needed in order to support the features presented in Section 2.

The term ontology originates from philosophy where it is used as the name of the study of the nature of existence [GR93]. In the context of computer science, the commonly used definition is "An ontology is an explicit and formal specification of a conceptualization" [AH04]. So it is a general vocabulary of a certain domain. Essentially the used ontology must be shared and consensual terminology as it is used for information sharing and exchange. On the other hand, ontology tries to capture the meaning of a particular subject domain that corresponds to what a human being knows about that domain. It also tries to characterize that meaning in terms of concepts and their relationships.

Ontology is typically represented as classes, properties attributes and values. So they also provide a systematic way to standardize the used metadata items. Metadata items describe certain important characteristics of their target in a compact form. The metadata describing the content of a document (e.g., an electronic prescription) is commonly called semantic metadata. For example, the keywords attached to many scientific articles represent semantic metadata

Each ontology describes a domain of discourse. It consists of a finite set of concepts and the relationship between the concepts. For example, within electronic prescription systems patient, drug, and e-prescription are typical concepts. These concepts and their relationships are graphically presented in Figure 3.

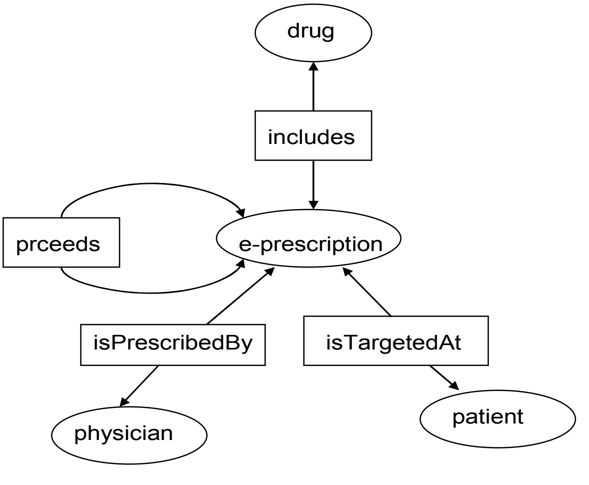

Figure 3. An e-prescription ontology.

In Figure 4 the ontology of Figure 3 is extended by instances, i.e., it includes the instances of the classes *physician, patient* and *e-prescription*

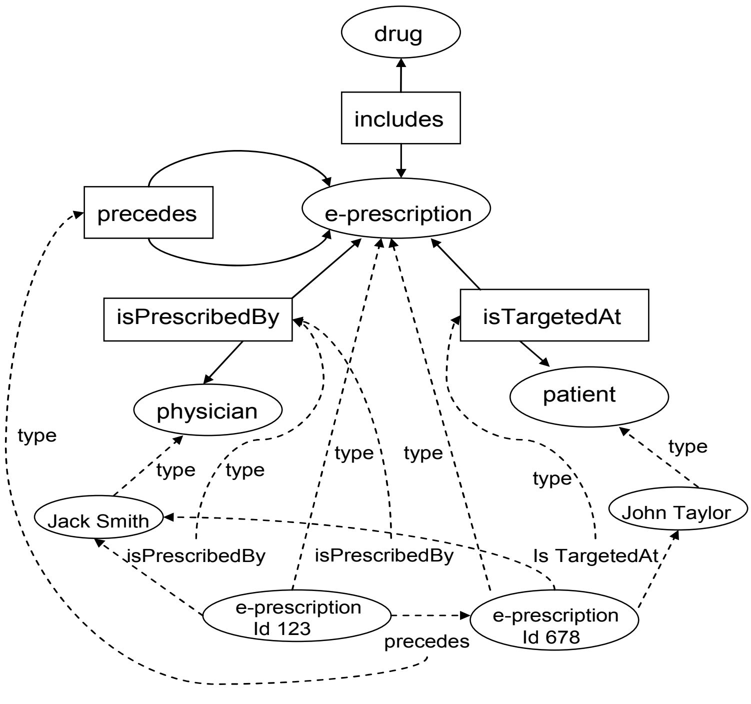

Figure 4. An extension of the e-prescription ontology.

The ontology of Figure 4 allows a wide variety of queries including:

- Give me all prescriptions prescribed to Jack Taylor
- Give me all prescriptions prescribed by physician John Smith
- Give me all prescriptions including drug named Panadol.

The most commonly used ontology languages are XML [HS02], XML Schema [HS02], RDF [DO03], RDF Schema [DO03] and OWL [SH05].

XML (Extensible Markup Language) [HS02] is a metamarkup language for text documents. It is the syntactic foundation layer of the Semantic Web. All other technologies providing features for the Semantic Web will be built on top of XML. Particularly XML defines a generic syntax used to mark up data with simple human readable tags. An important feature of XML is that it does not have a fixed set of tags but it allows user to define tags of their own. For example, various communities have defined their specialized vocabularies (set of tags) for various domains such as MathMl for mathematics, BSML for bioinformatics and GovML (Governmental Markup Language) for government.

For example using XML we can represent an electronic prescription as follows:

```
<Prescription>
        <Patient>
                <Patient_name>John Taylor </Patient name>
                <Identification> 5765766677</Identification>
                <Medicine>
                        <Medicine_name>Panadol</Medicine>
                        <Disease>fewer</Disease>
                        <Quantity>30</Quantity>
                        <Refills>1</Refils>
                        <dose>One tablet three times a day</dose>
                </Medicine>
        </Patient>
</Prescription>
```

Figure 5. A prescription in XML

In this illustrative XML-document we have used tags “Prescription”, “Patient”, “Identification”, ”Medicine”, “Disease”, “Quantity”, “Refills”, and “Dose”

XML Schema [HS02] is a language for restricting the structure of XML documents. It has two roles: First it is a template for a form generator (e.g., prescription writer) to generate instances of specific document type (e.g., prescription type). Second, it is a validator to ensure the accuracy of documents such as transmitted electronic prescriptions.

One characteristic of XML Schema is that its syntax is based on XML itself. A nice feature of XML-Schema is also that one can define new XML-Scheme by extending or restricting already existing scheme. In addition XML Schema provides a sophisticated set of data types that can be used in XML documents. So, for example, if there is a need for extending the prescription by the address of the patients, we only have to extend the XML Schema of the prescription document, i.e., we add the address element to the XML-Schema.

An XML document is well-formed if it complies with all the W3C syntax rules of XML [HS02]. This requirement guarantees that an XML processor can break into identifiable components the document. Further, XML-document is valid if it references and satisfies an XML Schema [HS02]. In our architecture (Figure 1), this means that there is such an XML processor at each communication unit. So for example, when the prescription holding store receives an electronic prescription it first checks the validity of the prescription and stores the prescription only if it valid.

While XML documents attach metadata to parts of the documents, one use of RDF (Resource Description Framework) [DO03] is to create metadata about the document as a standalone entity. To illustrate this we can for example state by an RDF statement that a prescription (e.g., the prescription of Figure 5) is prescribed by physician Jack Smith

The RDF model [DO03] is called a triple because it has three parts: *subject, predicate* and *object.* Each triple is an RDF-statement. The preceding statement about Jack Smith is such a statement: "*the prescription"* is the subject, "*isPrescribedBy"* is the predicate, and "*Jack Smith"* is the object. In order that RDF-statements can be represented and transmitted it needs syntax. The syntax has been given in XML. So an RDF-statement can be represented as an XML-document.

RDF Schema [DO03] provides the vocabulary for the RDF-statements. For example in our case," *isPrecribedBy"* is an item of our vocabulary. In the stack of the Semantic Web RDF-Schema is a language layered on top of RDF. It allows creating classes of data. A class is a group of things with common characteristics. For example, we have specified class *e-presciption, patient* and *physician*. Then by an RDF statement we can for example, specify that physician Jack Smith is an instance of the class *physician*, and by another RDF statement we can specify that prescription no. 72543 is an instance of the class *e-prescription*.

RDF Schema is a weak ontology language in the sense that it offers only the modelling concepts *class, subclass relations, property, subproperty relation* and *domain* and *range restrictions*. There are many modelling primitives that are useful in modelling documents in health care sector but are missing from RDF Schema. For example, neither we can specify that classes (e.g., *physicians* and *patients*) are not necessary disjoint nor can we build new class by set operations, e.g., class *doctors* is the union of the classes *physicians* and *dentists*. However, these kinds of features can be declared by the OWL (Web Ontology Language) [SH05].

5 Conclusions

Electronic prescription is the electronic transmission of prescriptions of pharmaceutical products from legally professionally qualified healthcare practitioners to registered pharmacies. The scope of the prescribed products varies from country to country as permitted by government authorities or health insurance carriers. For electronic prescription to be accepted by the physicians, pharmacies and patients it must provide added benefits to all participants.

In particular, electronic prescription systems have significant potential to improve the quality of medication prescription and contribute to reduction of medication errors. Therefore, during the past few years several organizations in the healthcare sector have produced standards and representation forms using XML. For example, patient records, blood analysis and electronic prescriptions are typically represented as XML-documents. This generalization of XML-technologies sets a promising starting point for the interoperability of the various organizations in the healthcare sector. However, the introduction of XML itself is not enough but also many other XML-based technologies have to be introduced in order to achieve a seamless interoperability between the organizations within the healthcare sector.

Today, in electronic prescription systems there is a great diversity in technological solutions. The solutions differ in many ways including the architecture of the EPS, used security policy, how the prescriptions are stored for further analysis, and how XML-based technologies are utilized. We can also make the distinction between electronic prescription systems depending on whether their main goal is to reduce the costs of medications or whether the main goal improving the quality of medications

In this article we have illustrated the interoperability within the healthcare sector from electronic prescriptions point of view. In particular, we illustrated how XML-based technologies can be utilized in modelling the concepts that are related to prescription writing, and how web-service technology can be used in implementing the interoperability of electronic prescription system and other healthcare systems.

A consequence of introducing Semantic Web technologies in health care sector is that it significantly changes the daily duties of the employees of the health care sector. Therefore the most challenging aspect will not be the technology but rather changing the mind-set of the employees and the training of the new technology.

The introduction of a new technology is also an investment. The investment on new Semantic Web technology includes a variety of costs including software, hardware and training costs. Training the staff on Semantic Web technology is a big investment, and hence many organizations like to cut on this cost as much as possible. However, the incorrect usage and implementation of a new technology, due to lack of proper training, might turn out to be more expensive in the long run.

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