Maintaining the Consistency of Electronic Health Record's Medication List

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Abstract: An electronic health record (EHR) is a systematic collection of health information about an individual patient. It includes a variety of types of observations entered over time by health care professionals, recording observations and administrations of drugs and therapies, orders for the administration of drugs and therapies, and test results. A well known problem is the consistency of EHR's medication list: often some of the prescribed drugs are missing, or some information is no more valid, e.g., some prescribed drugs may be replaced by new drugs, or the dosage may be changed. In this paper we have focused on this problem. We have restricted on EHRs and on prescriptions that are applications of the HL7 Reference Information Model (RIM). Further, we have used the Refined Message Information Model (RMIM) to specify the components that are extracted from prescriptions and transmitted into EHR. We have also specified the criteria for medication list's consistency, and the way it can be maintained. In addition, we have studied the ways the RIM can be used in linking patient's prescriptions among themselves such that the name of the link indicates its semantics. By viewing patient's prescriptions as a linked data structure we can improve the effectiveness of prescriptions' retrieval as well as provide expressive queries on patient's health documentation.

1 INTRODUCTION

An electronic health record (EHR) describes the systematic documentation of a single patient's medical history (Hartley and Jones, 2005). The main goal of an EHR is to provide a complete and accurate summary of the health and medical history of a patient (NEHTA, 2006). It includes a variety of types of observations entered over time by health care professionals, recording observations and administrations of drugs (Angst et al., 2008).

A well known problem is that EHRs' medication history is often out of date in the sense that some of the prescribed drugs are missing, or some information is no more valid, e.g., some prescribed drugs may be replaced by new drugs, or the dosage may be changed (Puustjärvi and Puustjärvi, 2011). So, there is a risk for physician's wrong diagnosis or treatment decision.

In this paper we have focused on this problem. We have studied how relevant medication data can be extracted from prescriptions and transmitted to the EHR such that the sender and receiver can unambiguously interpret the semantics of the exchanged messages.

It is not necessary to store the whole prescription into an EHR as it is just a summary of the health and medical history of a patient. For example, we have omitted the context information of a prescription such as who created it, when, where and for what purpose. Yet the physician can retrieve such information by following the link from the EHR to the original prescription that is stored in a prescription holding store. Anyway, storing the information of prescribed drugs and dosages into EHRs is of prime importance. Then a physician may present data centric queries such as the average blood pressure and/or cholesterol level during the time periods the patient was using Emconcor (a drug for blood pressure).

There are many standards, such as HL7 CDA (HL7, 2004), EN 13606 (prEN13606, 2006) and openEHR (openEHR, 2013) developed to digitally represent clinical data. Nowadays EHR systems increasingly use CDA's CCD standard (CCD, 2009) although it original purpose was to deliver clinical

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summaries between healthcare organizations (Benson, 2010).

With respect to the standards, we have restricted on EHRs and on prescriptions that are applications of the HL7 Reference Information Model (RIM), i.e., they are based on the same terminology. Further, we restricted on EHRs based on the CCD standard as it is nowadays increasingly used for storing medical summaries.

In order to achieve semantic interoperability between the prescription holding store and the EHR system we have to specify the semantics of the exchanged message. In specifying the data elements that are extracted from prescriptions and transmitted to EHR we constrained the conceptual model of the prescription, i.e., we constrained the Refined Message Information Model (RMIM) of the prescription.

Defining messages by RMIMs is a central idea of the HL7 V3 approach (HL7, 2007). Each RMIM diagram is derived from the RIM by limiting its optionality in the sense that the designer can take only the needed classes and attributes. Such constrained specifications are called *profiles*. Hence, EHRs based on CCD-standard, prescriptions as well as the messages transmitted to EHR have profiles.

We have also studied the ways the RIM provides for linking EHRs to prescriptions as well as linking prescriptions among themselves such that the name of the link (e.g., replaces) indicates the meaning of the link. By viewing patient's prescriptions as a linked data structure we can improve the effectiveness of prescriptions' retrieval as well as provide expressive queries on patient's health documentation.

The rest of the paper is organized as follows. In Section 2, we first give a scenario of an electronic prescription process, and then we give our interpretations of the prescription concept. In Section 3, we describe the prescription process from communication architecture point of view, i.e., we present the systems that are involved in prescription process. In Section 4, we first give an overview of the RIM, and then we illustrate how it is constrained in modelling prescriptions as well as the messages transmitted to the EHR.

In Section 5, we first present the structure of the CCD documents, and then we describe how its medication list can be linked into prescriptions according to the modelling primitives of the RIM. We also present our introduced notions of medication list's consistency and the ways it can be maintained. In addition, we discuss the suitability of our ideas for maintaining the consistency of personal health records. Finally, Section 6 concludes the paper by shortly discussing our future research.

2 PRESCRIPTION

Unfortunately there is no commonly used exact interpretation of prescription concept. For example, if the dosage of a prescription is changed or the prescription is renewed whether we have modified the existing prescription or whether we have produced a new one?

We have adopted the interpretation that once the prescription is stored in a prescription holding store it cannot be changed. Yet, a prescription may be invalidated and replaced by a new prescription. Hence prescriptions may have mutual dependencies which give rise for maintaining appropriate data structures among patient's prescriptions.

Our argument for not allowing prescriptions to be changed is to avoid confusions. For example, if a prescription is changed, then two physicians nay have different views of the same prescription. In addition, we only allow a prescription to be replaced ones. However, the length of the replacement chain is not restricted. The only requirement is that the chain may not be cyclic as it indicates an error.

If a replaced prescription is retrieved, then the whole replacement chain is presented for the user. This ensures that the user can make the distinction between valid and out date information in prescriptions.

We have also made the distinction between *active* and *passive prescriptions*: A prescription is active, if all its prescribed drugs are not yet dispensed or if the course of the drugs is not finished; otherwise a prescription is passive.

Our argument is that passive prescriptions should not be deleted from patient's EHR. Otherwise, queries such as "Give me the average blood pressure during the time the patient was using drug A and drug B" would require that both drugs are included in active prescriptions.

3 THE ARCHITECTURE OF THE SERVICE ORIENTED EPW

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 (Singh and Huhns, 2005). 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 to be composed.

In the health care sector service oriented computing provides flexible methods for connecting electronic prescription system to other relevant health care systems (Puustjärvi and Puustjärvi, 2012). For example, electronic prescription writer can interact through a Web service 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 Web services and SOAP-protocol (SOAP, 2012). Originally they provided a way for executing business transactions in the Internet. 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. Each component communicates through a Web service interface (WS-interface). Further, each message is presented as an XML-document, which is carried by the SOAP protocol.

Although in this architecture EPW extracts relevant data from prescription and transmits it to the EHR system, we can also easily modify the architecture such that the prescription holding store carries out this function, i.e., transmits the extracted data into the EHR. This functionality may also be

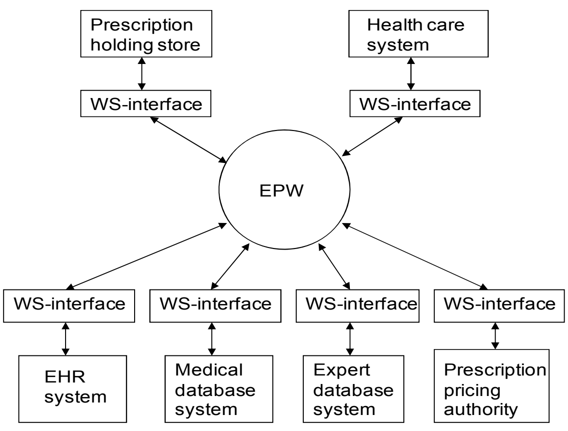

Figure 1: The Communication Architecture of the EPW.

EPW specific, i.e., depending on the EPW either it or the prescription holding store transmits the extracted data into the EHR. The analysis presented in forthcoming sections is valid for all these architectural choices.

4 MODELLING PRESCRIPTIONS AND EXCHANGED MESSAGES BY RMIMS

4.1 Reference Information Model Rim

The Reference Information Model RIM is the cornerstone of the HL7 Version 3 development process (Boone, 2011). It is the root of all information models and structures developed as part of the V3 development process.

The RIM is based on two key ideas (Benson, 2010). The first idea is based on the consideration that most healthcare documentation is concerned with “happenings” and things (human or other) that participate in these happenings in various ways.

The second idea is the observation that the same people or things can perform different roles when participating in different types of happening, e.g., a person may be a care provider such a physician or the subject of care such as patient.

As a result of these ideas the RIM is based on a simple backbone structure, involving three main classes, *Act*, *Role*, and *Entity*, linked together using three association classes *Act-Relationship*, *Participation*, and *Role-Relationship* (Figure 2).

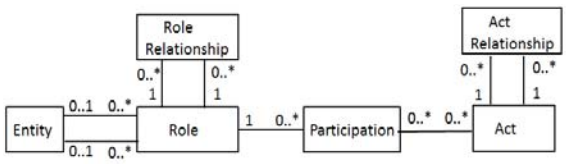

Figure 2: The RIM backbone structure.

The classes in the RIM have structured attributes which specify what each RIM class means when used in a message (exchanged document). The idea behind structured attributes is to reduce the original RIM from over 100 classes to a simple backbone of six main classes.

Each happening, such as prescribing medication or any CDA document is an Act, and it may have any number of Participations, which are Roles, played by Entities. An ACT may also be related to other Acts via Act Relationships, i.e., it links Acts together. Further, every ActRelationship has a source and target to which it points, and each Act may have any number of AcRelationships. Its typeCode, which is a structural attribute, describes the type of association between Acts. These are Composition (COMP), Documents (DOC), Fulfils (FLFS), Refers (REF), and Replaces (REP).

The typeCodes REF and REP play a central role in our solution: We use typeCode REF in linking the medication list of an EHR to prescriptions, and typeCode REP in linking prescriptions among themselves.

4.2 Refined Message Information Model RMIM

The RIM is not a model of healthcare, nor is it a model of any message, although it is used in messages. The structures of messages are defined by constrained information models. The most commonly used constrained information model is the Refined Message Information Model (RMIM). Each RMIM is a diagram that specifies the structure of an exchanged message.

Each RMIM diagram is derived from the RIM by limiting its optionality by omission and cloning (Benson, 2010). *Omission* means that the RIM classes or attributes can be left out. Note that all classes and attributed that are not structural attributes in the RIM are optional, and so the designer can take only the needed classes and attributes. *Cloning* means that the same RIM class can be used many times in different ways in a profile. For example, Patient and Employee are specializations of Role, and so they may both appear in the same diagram.

The multiplicities of associations and attributes in the diagram are constrained in terms of repeatability and optionality. Further, code binding is used for specifying the allowable values of the used attributes.

To illustrate the relationships of the RIM and RMIM consider the RMIM diagram of Figure 3.

Note that HL7 uses its own representation of UML in RMIM diagrams: each class has its own color and shape to represent the stereotypes of these classes, and they only connect in certain ways.

The entry point of this diagram (Prescription) is SubstanceAdministration, which is a specialization of the RIM class Act. Replaces is a specializations of the association class ActRelationship. Patient and Employee are specializations (subclasses) of the RIM class Role. Person and Organization are specializations of the RIM class Entity. Subject and Performer are specializations of the association class

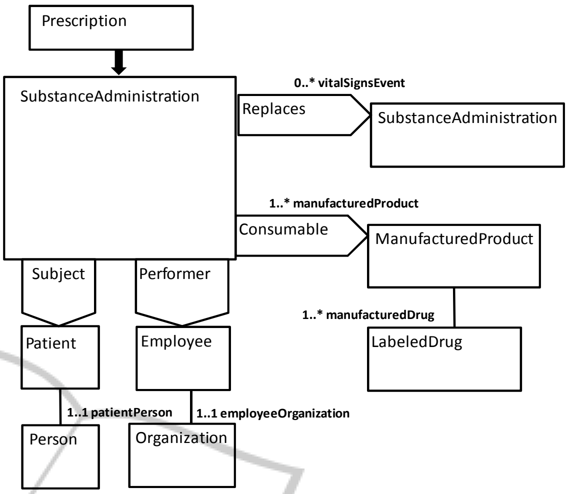

Figure 3: The RMIM of a simplified prescription.

Participation.

The diagram (drugsInPrescription) in Figure 4 specifies the RMIM for the message that the prescription holding store (or EPW) transmits to the EHR system. It is specified by constraining the RMIM of the prescription by omission. In particular the context information is left out from the prescription.

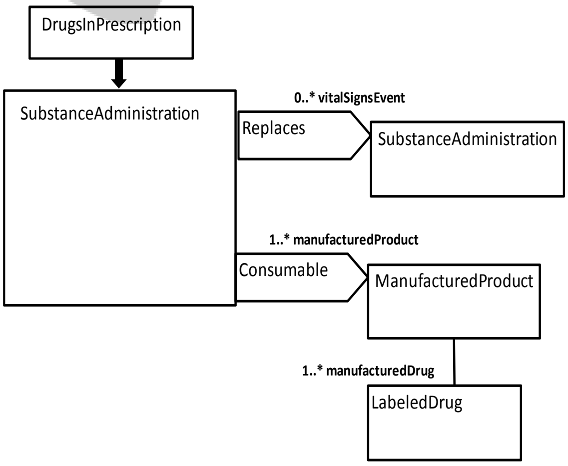

Figure 4: The RMIM of the message transmitted to EHR.

The XML-schemas of the exchanged messages are derived from the RMIM such that the class and attribute names of the diagram are the names of the elements of the XML-schemas. So, the RMIM diagram gives the semantics for the tags (elements) of the exchanged messages.

5 CONTINUITY OF CARE DOCUMENT

5.1 CDA and CCD Standards

The HL7 Clinical Document Architecture (CDA) is an XML-based markup standard intended to specify the encoding, structure and semantics of clinical documents for exchange (Boone, 2011). It is based on the HL7 RIM, meaning that we can interpret the semantics of its tags of the XML-documents by the RIM.

Each CDA document has one primary purpose (which is the reason for the generation of the document), such as patient admission, transfer, or inpatient discharge. The CCD specification is a constraint on the HL7 CDA standard. The CCD standard has been endorsed by HIMSS (Healthcare Information and Management Systems Society Though) (HIMSS, 2013) and HITSP (Healthcare Information Technology Standards Panel) (HITSP, 2013) as the recommend standard for exchange of electronic exchange of components of health information.

Although the original purpose of the CCD documents was to deliver clinical summaries between healthcare organizations, nowadays it increasingly used for other types of messages: it is considered as set of templates because all its parts are optional, and it is practical to mix and match the sections that are needed (Benson, 2010). Hence, there is a RMIM behind each CCD document.

5.2 The Structure of a CDA Document

A CCD document, as well as any CDA document, is comprised of the *Header* and the *Body* (Benson, 2010). A simplified Level 3 CCD document including the Header and the Medications section is presented in Figure 5. The simple element REF in the complex element Medication provides the link to the original prescription. Note that there is only one Medication element in the Medications element, and so there is only one link (REF-element) in the document.

```
<SimplifiedCCDfile>
  <DocumentID>DOC_123</DocumentID>
  <Patient>
    <PatientID>AB-12345></PatientID>
    <PatientName>Tim Jones></PatientName>
  </Patient>
  <Medications>
    <Medication>
     <REF>Prescription-123</REF>
      <MedicationID>Medication.567</MedicationID>
      <DateTime>
        <ExactDateTime>
              2012-03-01TO12:00
        </ExactDateTime>
      </DateTime>
       <Source>
        <Actor>
          <ActorID>Pharmacy of Kaivopuisto</ActorID>
          <ActorRole>Pharmacy</ActorRole>
        </Actor>
      </Source>
      <Description>
        <Text>One tablet three times a day</Text>
      </Description>
      <Product>
        <ProductName>Voltaren</ProductName>
        <BrandName>Diclofenac</BrandName>
      </Product>
      <Strenght>
        <Value>50</Value>
        <Unit>milligram</Unit>
      </Strenght>
      <Quantity>
        <Value>30</Value>
        <Unit>Tabs</Unit>
      </Quantity>
    </Medication>
  </Medications>
</SimplifiedCCDfile>
```

Figure 5: A simplified example of a CCD document.

5.3 The Consistency of CCD's Medication List

We say that CCD document's medication list (Medications element) is *well-formed,* if each Medication elements includes a link (i.e., REF-element) to a prescription. It is *exhaustive*, if patient's all prescriptions are linked into the EHR. Further if, the medication list is well-formed and exhaustive, we say that it is *consistent*.

Whether the medication list is well formed can be easily checked from patient's EHR. Instead whether it is exhaustive requires also accessing patient's prescriptions from prescription holding store. However, assuming that the prescription holding store follows the practise of linking its prescriptions into EHRs, then there is no need for such a checking.

6 CONCLUSIONS

As a patient may live in many places and use many healthcare specialities, patient's clinical documents are often stored in several systems and locations. However, patient's all relevant documents should be easily accessible for the physicians treating the patient. Hence the EHRs, which provide a complete and accurate health and medical history of a patient is of prime importance.

EHR systems usually organize clinical documents into hierarchical structures that simplify the search of documents, e.g., grouping together the documents by episode, clinical specialty or time period. Further, each clinical document is stored as a stand-alone artefact, meaning that each document is complete and whole in itself, including context information such as who created it, when and where and for what purposes. Without such contextual information in some cases it may be a risk to interpret some values of the data included on a document.

On the other hand, considering each document only as a complete and a whole in itself also has its drawback. The problem here is that the efficient usage of patients' health documentation often is data centric, meaning that data should be extracted from various documents and then integrated according to specific criteria. For example, a physician may be interested to know the average blood pressure and/or cholesterol level during the time periods the patient was using a drug for blood pressure. Hence the medical summaries such as the CCD documents are of prime importance. However, maintaining the consistency of the CCD documents is not an easy task as it requires the interoperation of several systems.

The key point in our presented solution for achieving the consistency of CCD documents' medication list is the semantic interoperability between the prescription holding store and the EHR system. Yet medication list is just a component of an EHR. Ensuring the consistency of the other components of the EHR is equally important. This suggests that the semantic interoperability of the EHR system and other systems that produce clinical documents for the EHR is also of prime importance. In our future research we will focus on this topic.

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