# Using Ontology-based Registry and SPARQL Engine in Searching Patient's Clinical Documents

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Abstract: 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. In order to alleviate this problem, an industry initiative IHE XDS allows health care documents to be shared over a wide area network, between hospitals, primary care providers, and social services. Its main innovation is the logical and physically separation of the indexing information used to retrieve documents from the actual content. Technically the XDS document registry is a subset of the ebXML Registry standard, and documents are exchanged using SOAP and HTTP, while SQL is used for information retrieval. Although IHE XDS has proven to be useful and workable innovation, we have investigated whether the technologies behind the IHE XDS could be replaced by new technologies such as by OWL-based registries and SPARQL engines. It turned out that these technologies enable the introducing simpler policies in document exchanges. For example, contrary to the IHE XDS, we do not have to expect patients' records to follow then when they move from one affinity domain to another. Instead one SPARQL query processed by a SPARQL engine is able to composing the links to patient's original clinical documents.

## 1 INTRODUCTION

An electronic health record (EHR) describes the systematic documentation of a single patient's medical history and care across time within one particular health care provider's jurisdiction (Hartley and Jones, 2005). 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, test results, x-rays, and reports.

There are many standards, such as HL7 CDA (HL7, 2004), EN 13606 (prEN13606, 2006) and openEHR (openEHR, 2013) developed to digitally represent clinical data. These standards aim to structure and markup the clinical content for the purpose of exchange (NEHTA, 2006).

A well-known problem is that patient's EHRs are often stored in several systems (Puustjärvi and Puustjärvi, 2009). This is a consequence of living in various places, and having many healthcare providers, including primary care physician, specialist, therapists and other medical practitioners. However, although patient's clinical documentation is stored in several EHR systems all relevant documents should be easily accessible for the physicians treating the patient.

The problem of patients' scattered clinical documents is studied in the context of Personal Health Records (PHRs) (Raisinghani and Young, 2008), EHR archives (Hartley and Jones, 2005) and IHE XDS (IHE, 2005). With PHRs and EHR copies of patient´s health documentation is collected together in advance while in IHE XDS original documents are dynamically retrieved by exploiting relevant registries.

In IHE XDS terminology healthcare enterprises that agree to work together for clinical document sharing is called *clinical affinity domain*. Its enterprises agree on a common set of policies such as how the patients are identified, the access is controlled, and the common set of coding terms to represent the metadata of the documents. Further, patients expect their records to follow them as they move from one clinical affinity domain to another.

Examples of XDS clinical affinity domains include: nationwide and regional EHRs, federations

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of enterprises, regional federations made up of several local hospitals, healthcare providers, and insurance provider supported communities

The key point in IHE XDS is the logical and physically separation of the indexing information used to retrieve documents from the actual content. The document registry indexes documents, support document search, and maintains a URI link back where the document is stored in a document repository. The basic XDS has been refined to support special requirements for DICOM images, structured laboratory reports, and HL7 CDA medical summaries (CCD, 2009). The format of the used metadata is largely based on HL7 Version 2 (Dolin et al., 2001). Technically the XDS document registry is a subset of the ebXML Registry standard (ebXML, 2012), and documents are exchanged using SOAP and HTTP (Singh and Huhns, 2005), while SQL (Ullman and Widom, 1997) is used for information retrieval in registries.

Although the IHE XDS has proven to be useful and workable innovation, we argue that by exploiting modern information technology we can avoid many of the drawbacks of the IHE XDS. In particular, we have addressed the following two problems of the IHE XDS.

The main problem with ebXML registries is that searches can only be based on the keywords and folders. Although the keywords are taken from a taxonomy only a very limited amount of semantics can be provided (Dogac et al., 2007). Folders group the related documents together (e.g., based on a period of time, episode, or immunizations). However, there are numerous cases where retrieving predefined folders are not appropriate but rather dynamic grouping of documents should be possible.

Another problem with the IHE XDS is that it expects patients' records to follow then when they move from one affinity domain to another. The problem here are twofold: First, moving records between affinity domains is technically complicated and error-prone due to the heterogeneities of affinity domains. Second, due to the failed or missed transmissions patients' EHRs are incomplete.

We have designated a registry mechanism for clinical documents that eliminates these drawbacks. The expression power of document retrieval is increased by introducing a specific OWL-ontology (OWL, 2011), called *Registry Ontology*, for document retrieval. It is derived from the class diagram on which the Header of the HL7 CDA documents (Boone, 2011) is based on. The primary purpose of the CDA Header is to provide unambiguous, structured metadata about the document itself, which can be used in document registers to classify, find and retrieve documents.

In our solution, the exchange of documents between clinical affinity domains is eliminated by retrieving all clinical documents from their original sources. Such a feature can be carried out by the Registry ontology and the Federated Queries supported by SPARQL engines (SPARQL, 2008). A useful feature of Federated Queries is that within a query many registries can be accessed.

The rest of the paper is organized as follows. First, in Section 2, we consider the basic components of the IHE XDS architecture. In Section 3, we present the way the Registry Ontology is derived. First, we give an overview of the HL7 RIM, and the ways the RMIMs (Refined Message Information Models) are derived from the RIM. Then, we present the RMIM on which the Header of the CDA documents is based on, and transform it into OWL ontology (i.e., to Registry Ontology). Further, in Section 4, based on the ontology we present a SPARQL query which retrieves the URLs of patients' documents that are stored in two repositories. Section 5 concludes the paper by discussing our future work.

# 2 IHE XDS

## 2.1 IHE XDS Architecture

Integrating Healthcare Enterprise (IHE) was established in 1999 by the Healthcare Information Systems and Management Society (HIMSS) and the radiological Society of North America (RSNA) to improve the way healthcare computer systems share information (IHE, 2005). It is not a standards organization. Instead it promotes coordinated use of existing standards to develop workflow solutions for the healthcare enterprises. IHEs starting point was radiology, where it developed profiles which specify how to use DICOM and HL7 together, and later on it has moved to cardiology, clinical laboratories, and other specialities.

Another dimension of IHE's work has been the development of IT infrastructures standards for use across departmental and institutional boundaries. The IHE XDS profile is an example of this. Systems designed in agreement with IHE profiles communicate better with one another, and facilitate efficient access to information.

The idea behind the IHE XDS is to build virtual patient records on the fly from a variety of clinical documents created by different healthcare organizations (Benson, 2010). The separation of the metadata (indexing information) used to retrieve documents from the actual content allows IHE XDS to handle any type of content and simplifies the addition of an XDS export function to existing systems. Thereby each document is viewed in its original form.

The components of the IHE XDS are *document source*, *document repository*, *document registry* and the *document consumer*. The IHE XDS architecture within one affinity domain is presented in Figure 1.

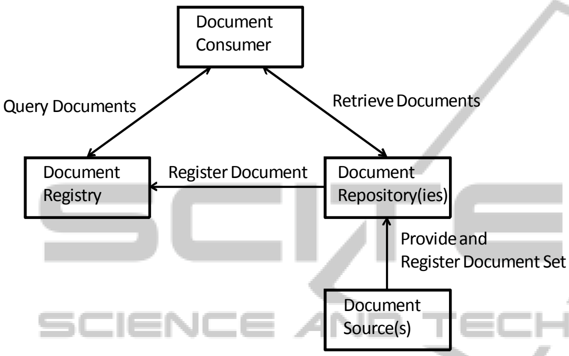


Figure 1: IHE XDS architecture.

The document source produces original documents, submits these to a document repository, and also produces metadata about each stored document which is sent to the document registry. There may be one or more document repositories and each provides secure document storage and supports document retrieval. Documents may be organized in folders.

The document registry indexes documents, support document search, and maintains a URI link back where the document is stored in a document repository. The document consumer is a user system. It initiates searches of the register, retrieves and displays selected documents from their repositories.

## 2.2 ebXML Registry Information Model

The ebXML Registry Information Model defines what types of objects are stored in the registry and how they are organized (Dogac et al., 2007). Figure 2 represents the hierarchical structure of the ebXML registry constructs.

Top level class "RegistryObject" provides minimal metadata for registry objects. Other instances are used to provide a dynamic way to add arbitrary attributes to "RegistryObject" instances. For example, Association instances can be used to define many-to-many associations between objects

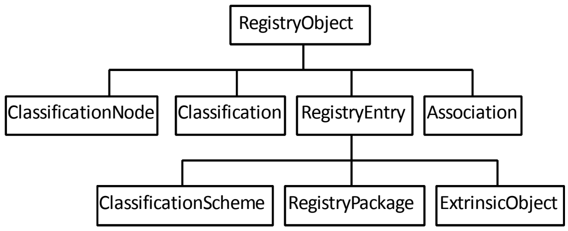


Figure 2: Components of the ebXML Registry Information Model.

in the information model. Further, each association has an "associationType" attribute that identifies the type of that association.

There are also many predefined Association Types and new types can be introduced when needed. As a result the ebXML RIM structures enable the specification of conceptual schemas. Further "ClassificationScheme" instances describe a structured way to classify and categorize RegistryObject instances. RegistryPackage instances group logically related RegistryObject instances together, and thus enable the specification of the folders of the clinical documents.

## 2.3 Enhancing IHE XDS

To facilitate information exchange between heterogeneous clinical affinity domains the IHE XDS is enhanced in (Dogac et al., 2002) by a specific ontology which enables the mappings between heterogeneous affinity domains. The ontology is first specified in OWL, and then transformed in the format of ebXML Registry Information Model, and finally it is transformed into relations and stored in the ebXML registries that can be queried by SQL.

Thus the document discovery across affinity domains is facilitated through ontology mappings when affinity domain specific metadata is defined through the ontology (Dogac et al., 2007). The introducing of the ontology enables the specification of the associations between the nodes. The associations are defined by modeling primitives supported by the ebXML Registry Information Model, and are stored in the Registry.

# 3 HL7 CLINICAL DOCUMENT ARCHITECTURE

## 3.1 HL7 Reference Information Model

The HL7 Reference Information Model (RIM) is the cornerstone of the HL7 message development process and development methodology (Puustjärvi and Puustjärvi, 2010). It expresses the data content needed in a specific clinical or administrative context and provides an explicit representation of the semantic and syntactical connections that exist between the information carried in the fields of HL7 messages (Boone, 2011).

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 3). Note that HL7 uses its own representation of UML to reflect the use of these six backbone classes. Each class has its own color and shape to represent the stereotypes of these classes, and they only connect in certain ways.

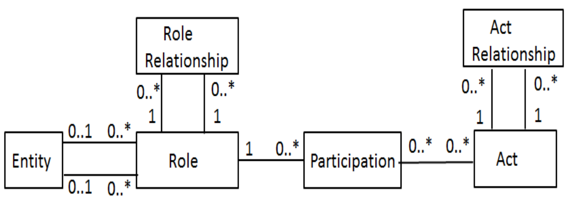


Figure 3: RIM backbone structure.

Each happening 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. Act, Role and Entity classes have a number of specializations (subclasses), e.g., Entity has a specialization LivingSubject, which itself has a specialization Person.

The classes in the RIM have structured attributes which specify what each RIM class means when used in a message (exchanged document). For example, Act has structured attributes classCode and moodCode. The former states what sort of Act this is (e.g., observation, encounter, or administration of a drug). moodCode indicates whether an Act has happened, is request for something to happen, a goal or a criterion. The idea behind structured attributes is to reduce the original RIM from over 100 classes to a simple backbone of six main classes (Benson, 2010).

## 3.2 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 exchanged messages. The structures of exchanged documents are defined by constrained information models (HL7, 2007). The most commonly used constrained information model is the RMIM. Each RMIM is a diagram that specifies the structure of an exchanged document.

A RMIM diagram is specified for a specific use case (Boone, 2011). The diagram is derived from the RIM by limiting its optionality. Such specifications are called CDA Profiles (Spronk, 2008).

In developing a RMIM diagram the RIM is constrained by omission and cloning. 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 various RMIMs. The classes selected for a RMIM are called clones.

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

Although the semantics of all CDA documents is tractable through a RMIM back to the RIM, we neither can use the RMIM nor the RIM in formulating queries on patient’s health documentation as each RMIM only models one type of documents. Another reason is that there are no query languages specified for the information model used in the RMIM and RIM schemas.

## 3.3 CDA Levels

Each Continuity of Care document (CCD) has one primary purpose (which is the reason for the generation of the document), such as patient admission, transfer, or inpatient discharge. Each Clinical Document Architecture (CDA) document is made up of the *header* and the *body* (Benson, 2010).

Depending whether the header and body of the CDA documents are based on the RIM they are classified into three levels:

- *CDA Level 1*: Only the header is based on the RIM while the body is human readable text or image.

- *CDA Level 2*: Only the header of the document is based on the RIM while the body is comprised of XML coded sections.

- *CDA Level 3*: Both the header and the body are based on the RIM.

The CDA header is common to all the three levels of CDA. The header contains basic metadata. These include information about what the documents is, who created it, when, where, and for what purposes. Its primary purpose is to provide unambiguous, structured metadata about the document itself, which can be used in document registers to classify, find and retrieve documents.

In HL7 CDA terminology the header is an instance of an Act called Clinical Document. This means that there is a Refined Message Information Model (RMIM) that models the headers of all HL7 CDA documents. To illustrate this, a simplified RMIM of the Header of CDA documents is presented in Figure 4. The diagram presents classes of the RMIM but not all their attributes.

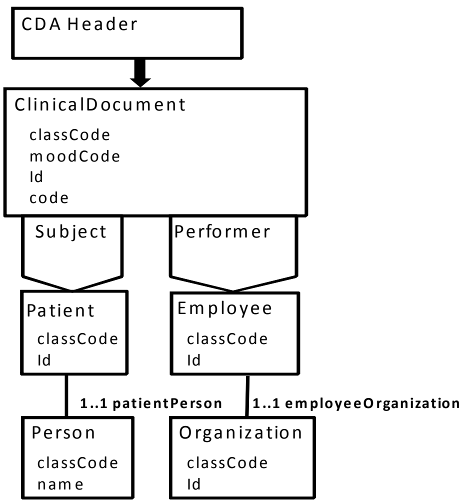


Figure 4: A simplified RMIM of CDA Header.

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

The entry point of this diagram (CDA Header) is ClinicalDocument, which is specialization of the RIM class Act. Classes 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 Participation. Each specialization inherits all of the properties (attributes) of the generalization. For example, the class Patient is a specialization of Role with the addition of the optional attribute veryImportantPersonCode.

## 3.4 Transforming HL7 CDA Header into OWL

Although the semantics of all CDA documents is traceable through a RMIM back to the RIM, we neither can use a RMIM nor the RIM in formulating queries as there are no query languages specified for the information model used in the RMIM and RIM schemas. For this reason we transform the RMIM of the CDA header into Web Ontology Language (OWL) (OWL, 2011).

Transforming a RMIM diagram into OWL is straightforward in the sense that both models are object-oriented although the notation used in RMIM diagrams slightly differs from the traditional UML notation. Yet their basic modelling primitives are the same, namely classes, subclasses, properties and values. The classes are also connected in a similar way through properties.

In order to illustrate the transformation of RMIM diagram into OWL we have presented the RMIM diagram of Figure 4 in OWL in Figure 5.

Classes, subclasses, data properties and object properties are modeling primitives in OWL (Antoniou and Harmelen, 2004). Object properties relate objects to other objects while datatype properties relate objects to datatype values (Daconta et al, 2003). For example, Performer is an object property. Its domain is clinicalDocument and range is employee. Note that, in Figure 5 we have omitted most datatype properties. The only datatype property presented in the figure is “code”. Its domain is clinicalDocumernt and its range is xsd:string, i.e., string in “XML-terminology”.

```
<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#>
 xmlns:xsd =http://www.w3.org/2001/xml-schemal#>
 <owl:Ontology rdf:about="registryOntology"/>
 <owl:Class rdf:ID="act/">
 <owl:Class rdf:ID="role/">
 <owl:Class rdf:ID="entity/">
<owl:Class rdf:ID="participation/">
 <owl:Class rdf:ID="clinicalDocument">
     <rdfs: subClassOf rdf:: resource "#act"/>
 </owl : class>
 <owl:Class rdf:ID="patient">
     <rdfs: subClassOf rdf:: resource "#role"/>
 </owl : class>
 <owl:Class rdf:ID="employee">
     <rdfs: subClassOf rdf:: resource "#role"/>
 </owl : class>
 <owl:Class rdf:ID="person">
      <rdfs: subClassOf rdf:: resource "#entity"/>
 </owl : class>
 <owl:Class rdf:ID="organization">
      <rdfs: subClassOf rdf:: resource "#entity"/>
 </owl : class>
 <owl:ObjectProperty rdf:ID="subject">
        <rdfs:domain rdf:resource="#clinicalDocument"/>
        <rdfs:range rdf:resource="#patient"/>
 </owl:ObjectProperty>
 <owl:ObjectProperty rdf:ID="patientPerson">
        <rdfs:domain rdf:resource="#patient"/>
        <rdfs:range rdf:resource="#person"/>
 </owl:ObjectProperty>
 <owl:ObjectProperty rdf:ID="performer">
        <rdfs:domain rdf:resource="#clinicalDocument"/>
        <rdfs:range rdf:resource="#employee"/>
 </owl:ObjectProperty>
 <owl:ObjectProperty rdf:ID="employeeOrganization">
        <rdfs:domain rdf:resource="#employee"/>
        <rdfs:range rdf:resource="#organization"/>
 </owl:ObjectProperty>
 <owl:DatatypeProperty rdf:ID="code">
         <rdfs:domain rdf:resource="#lclinicalDocument"/>
         <rdfs:range rdf:resource="&xsd;string"/>
 </owl:DatatypeProperty>
      .
      .
      .
</rdf:RDF>
```

Figure 5: A part of CDA Header in OWL.

# 4 QUERYING CLINICAL DOCUMENTS BY SPARQL

## 4.1 SPARQL Queries

The name SPARQL is a recursive acronym for SPARQL Protocol and RDF Query Language, which is described by a set of specifications from the W3C (DuCharme, 2011). SPARQL Protocol refers to the rules for how a client program and a SPARQL processing server exchange SPARQL queries and results.

A typical SPARQL query specifies the pieces of information that meets the stated conditions. The conditions are described with triple patterns, which are similar to RDF triples but may include variables to add flexibility in how they match against the data.

There is a variety of SPARQL processors (also called SPARQL engines) available for running queries against data both locally and remotely. SPARQL provides two ways for querying remotely: using FROM keyword or using SERVICE keyword. In the former way the FROM keyword names a dataset to query that may be local or remote file. In the latter way, instead of pointing at an RDF file somewhere, a SPRQL endpoint is pointed. A SPARQL endpoint is a web service that accepts SPARQL queries, runs the queries, and then returns the result.

## 4.2 Federated Queries

Federated Queries in SPARQL allow searching multiple datasets with one query. For each dataset is created a subquery which access datasets by using SERVICE keywords. That is, federated SPARQL queries make use of subqueries and SERVICE keywords. To illustrate this consider the federated SPARQL query presented in Figure 6. The query is based on the ontology presented in Figure 5, and the prefix *ro* in the query refers to that ontology. The query returns the addresses of Lisa Smith's clinical documents by accessing two datasets through SPARQL endpoints. The result of the query is the union of the results of the two subqueries.

```
PREFIX owl: <http://www.w3.org/2002/07/owl#>
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX ro: <http://www.cs.helsinki.fi/registryOntology#>
PREFIX pe : <http://www.healthstore/resource/people/>
SELECT ?documentAddress
WHERE
{
 SERVICE <http://documentRegistry_A/sparql>
 { SELECT ?id
   WHERE
   {
    pe:Lisa_Smith ro:subject ?id ;
   ?id ro:classCode ro:Observation ;
   ?id ro:code "71620000" .
   }
 }
  SERVICE <http://documentRegistry_B/sparql>
 { SELECT ?documentAddress
   WHERE
   {
   pe:Lisa_Smith ro:subject ?id ;
   ?id ro:classCode ro:Observation ;
   ?id ro:code "71620000" .
   }
 }
}
```

Figure 6: A simple federated SPARQL query.

This SPARQL query is based on the architecture presented in Figure 7. The query of Figure 6 presents the communication between the document consumer and the two document registries (denoted by “Query Documents” in the figure). Documents Registries provide SPARQL endpoints, which are web services.

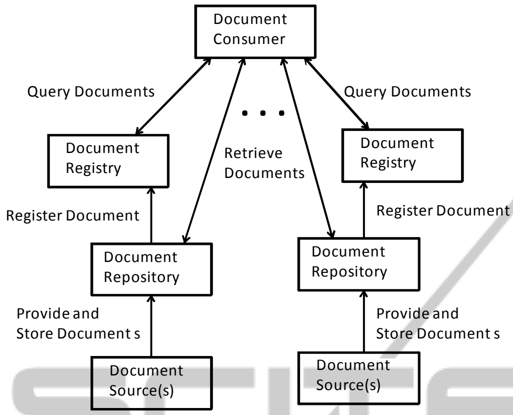


Figure 7: The Architecture of the communicating components.

Note that in our solution all document registries are accessed in querying the locations of patient’s documents. As a result, many of the registries are queried though they have no registry items of the patient. Such unnecessary queries could be avoided if the Document Consumer is informed about the relevant registries or a dictionary is maintained which includes such information.

# 5 CONCLUSIONS

Patient’s clinical documents are often stored in several healthcare providers’ systems. This is a consequence of living in various places, and having many healthcare providers, including primary care physician, specialist, therapists and other medical practitioners.

The problem of patients’ scattered clinical documentation can be managed by using personal health records, EHR archives and IHE XDS Registries.

The key point in IHE XDS is the logical and physically separation of the indexing information used to retrieve documents from the actual content. The document registry indexes documents, support document search, and maintains a URI link back where the document is stored in a document repository. Further, the Cross-Community Patient Discovery (XCPD) profile supports the means to locate communities which hold patient relevant health data and the translation of patient identifiers across communities holding the same patient’s data.

Although the IHE XDS has proven to be useful innovation, we argue that its used ebXML Registry standard does not provide enough semantics for indexing clinical documents. Instead, according to ebXML original purpose, its data structures are appropriate for indexing and classifying the web services of electronic business.

Our studies have shown that building a clinical document registry based on the class diagram of the HL CDA Header is a logical choice as its original purpose is to provide metadata for document registries. Further, SPARQL language and SPARQL engines provide an elegant way for accessing several registries within a query. As a result, we do not have to expect that patients’ records follow them as they move from one clinical domain to another.

For now, our proposed solution is restricted on CDA documents as they already provide sufficient metadata for the registries. However, our solution can be easily extended to other formats, such as DICOM and PDF, by annotating these documents in a way that is compliant with the CDA document header.

In our future work, we will investigate whether it is possible to extend the semantics of the Registry Ontology, which is now based on the CDA Header. The problem here is that the efficient usage of patients’ health documentation often is data centric, meaning that documents should be retrieved based on their content. For example, a physician may be interested to retrieve the documents dealing with Emconcor (a drug for blood pressure). However, the data required by such queries is not provided by the CDA Header but rather it is provided by the CDA Body. This suggests that it may be reasonable to extend the Registry Ontology by some elements taken from the CDA Body.

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