An Ontology-Based Electronic Medical Record for Chronic Disease Management

Ashraf Mohammed Iqbal, Michael Shepherd and Syed Sibte Raza Abidi
Faculty of Computer Science
Dalhousie University
Halifax, NS, Canada B3H1W5
{iqbal, shepherd, sraza}@cs.dal.ca

Abstract
Effective chronic disease management ensures better treatment and reduces medical costs. Representing knowledge through building an ontology for Electronic Medical Records (EMRs) is important to achieve semantic interoperability among healthcare information systems and to better execute decision support systems. In this paper, an ontology-based EMR focusing on Chronic Disease Management is proposed. The W3C Computer-based Patient Record ontology [7] is customized and augmented with concepts and attributes from the Western Health Infrastructure Canada chronic disease management model [2] and the American Society for Testing and Materials International EHR. The result is an EMR ontology capable of representing knowledge about chronic disease. All of the clinical actions of the proposed ontology were found to map to HL7 RIM classes. Such an EMR ontology for chronic disease management can support reasoning for clinical decision support systems as well as act as a switching language from one EMR standard to another for chronic disease knowledge.

1. Introduction

Chronic diseases are long-term and rarely cured, and have been identified as the leading cause of death the world over [1]. Chronic diseases are associated with huge medical care costs. Hence, effective chronic disease management is mandatory for cost reduction and quality care. Clinical information systems are crucial components in such management. An Electronic Medical Record (EMR) is the key component of a clinical information system to capture the longitudinal medical records of patients. An EMR can reduce errors in data entry, ensure timely accessibility of information by simultaneous multiple users, can be used to support reasoning in decision support systems, and can reduce care costs.

The knowledge representation of EMRs is very important to ensure semantic interoperability and to facilitate reasoning by decision support systems. In this research, we represent EMR knowledge as an ontology which focuses mainly on chronic disease management. Since, there are some differences between the information model of an EMR and the information model required for chronic disease management, the W3C proposed Computer-Based Patient Record (CPR) ontology [7] is customized and mapped onto the WHIC proposed chronic disease management model [2]. Our proposed ontology ensures a structured means for data entry by integrating controlled vocabulary from SNOMED-CT. Furthermore, the resultant ontology is mapped to HL7 RIM to capture the clinical messages written in HL7.

Our proposed EMR ontology is evaluated against standard ontology design principles [23, 24]. Two sample medical records represented in HL7 [25, 26] are instantiated using the proposed ontology. The evaluation results show that our proposed ontology has the capability to capture clinical records and can be used by decision support systems for reasoning purposes.

The rest of this paper is organized as follows: Section 2 discusses EMR standards currently available in the literature. Section 3 briefly presents the Chronic Disease Management Model proposed by WHIC. Section 4 summarizes the Computer-based Patient Record Ontology proposed by the W3C. Section 5 briefly describes the proposed ontology-based electronic medical record for chronic disease management Section 6 presents the results, and finally Section 7 summarizes the findings and concludes the paper.

2. Electronic Medical Record Standards

Extensive research is being carried out to develop comprehensive standard models for EMRs. These standard models provide a logical structure of information content. They also specify the relationship of this content to clinical concepts (architectural
standards), and specify the syntax and representation of EMR information to be interchanged. Open-EHR, CEN-EN 13606, and the Problem-Oriented Medical Record (POMR) are examples of standards for EMR logical structures, while HL7 provides the most widely used messaging standard among healthcare information systems.

Open-EHR [10] provides specifications for shared EMR, which is more “technology-based” than “standards-based” [8]. It consists of a two-level model, one level of which is a simple reference model (RM) and the other a formal constraints model called an archetype. The RM describes the basic structure of clinical information whereas the archetype models provide architectural standards for EMR information and share common clinical definitions specified in the shared Open-EHR archetype repository. Each archetype can be considered a model containing clinical content and can be expressed in a constraint formalism form. The information model is proposed as a separate model from the demographic information model and finally the Extract package is archetyped containing both of them. The most important package of this RM model is ‘ENTRY’ which is based on the Clinical Investigator Recording (CIR) ontology [12]. It is claimed to fill the greatest portion of the POMR [12].

CEN 13606, the European standard EMR, is based on the open-EHR archetype model. It is composed of five parts [18]: i) the RM defines the EHR information to be communicated, ii) the archetype interchange specification provides the generic model of information of archetype instances, iii) reference archetypes and term lists maintain the rules and associated data objects for EHR interaction, iv) security requirements and distribution rules specify the requirements and mechanisms of access rights of EHR components, v) exchange models describe a set of models for service based or message based communication. The archetypes can be represented in a standard format called Archetype Definition Language (ADL), which is compatible with HL7 RMIMs and CMETs [18].

The POMR was proposed by Weed in 1969 [11] as a means of storing medical data in a structured way to ensure its ready accessibility. This was a problem-centric theoretical model supported by another structure called SOAP used to take progress notes. There are four main components involved in constructing such EMR structures: the problem list, database, initial plans, and progress notes. The problem list contains the titled and numbered list of problem headings, the status of the problem, and the date of the first entry of the problem. It may also include a short description about each problem with information such as symptoms, laboratory investigations etc. Some socio-medico factors such as social problems, risk factors and psychiatric problems may also go under this list. The updates of problems go under the problem heading with the observation date. The database mainly contains information about previous clinical history. Although there is ongoing debate about the definition of the database, Weed suggested forming the database with the routine information that clinicians usually ask patients [13]. The initial plans reflect the initial goals in the practitioners’ minds after observing the patient and incorporate diagnostic lists, information to be monitored, probable therapy and patient’s education [13]. The progress notes (also known as follow-up notes) are captured in four sub-sections: Subjective (symptoms or absence of expected change), Objective (results of investigation), Assessment (notes based on the previous two sub-sections), and Plans (plans for further investigation/medication) [14].

There have been some successful implementations of POMR [15, 16]. Weed initiated computerized POMR in 1969, and in 1976 developed a hypertext EMR system called Problem-Oriented Medical Information System (PROMIS) [15]. The system was implemented using a touch screen for data entry by clinicians. Although it was observed that PROMIS was less time consuming for clinicians than using a standard paper format, it was not widely accepted mainly due to its non-conventional method of data entry. PKC [16] proposed the clinical sections for a patient: Screening, Health Maintenance, Medical Problems – Active, Medical Problems – Inactive and Assets with possible sub-sections under each of these (e.g., the sub-sections for active medical problems were goal, basis, status, disability, follow courses etc.). CPOMR supported both free text and coded data elements in data entry. In practice, the data elements in one hierarchical list may need to interact with those in another. This was not supported by the proposed CPOMR. The complete information model of their proposed CPOMR was not published by the authors.

The American Society for Testing and Materials (ASTM) International provided an EHR standard [18] mainly to define the attributes necessary for the successful implementation of an EHR. They adopted the traditional POMR approach and classified the clinical data into eight main categories: Patient, Problem, Encounter (contains encounter and referral information), Practitioner, Order/Plan (i.e., request for a procedure/observation and care plan), Service Instance (e.g., medications, immunizations and procedures), Observation (e.g., screening information, lab results, physical examination) and Service Master (master tables for ensuring controlled vocabulary of
attributes). They proposed 119 essential data elements under these clinical entities.

HL7 (Health Level-7) [9] is an ANSI-accredited standard providing organization. In version 3, they incorporated the Reference Information Model (RIM), an object model (with attributes, codes and vocabularies) for representing the logical relationships among different entities involved in a clinical information domain and for specifying the complete life cycles of events carried by shared messages. As well, HL7 provides an XML-based messaging standard called the Clinical Document Architecture (CDA) to specify the controlled architecture of contents in shared clinical documents. These CDA documents are both human and machine readable.

Currently available EMR standards are based on different structural perspectives while constructing the information models from different aspects. The information model of HL7 is the most widely used messaging standard. Among the EMR standards, HL7 is act-centric; Open-EHR and CEN EN 13606 information models are based on elements specified in archetypes; and POMR is problem-centric. Open-EHR and CEN EN 13606 have limitations in the sense that these are fully dependent in their controlled archetype repository. It is an ongoing research and development process to incorporate more archetypes and some practical scenarios which cannot be logically adjusted into current archetypes [8] (e.g., the episodic tracking of treatment). Traditional POMR also has some limitations such as lack of a suitable way to keep the narrative notes of healthcare professionals, and linking and relating among different problems. Moreover, the SOAP structure for progress notes might be unnecessarily complex for simple problems. Despite these and other drawbacks, a POMR-based information model can still adequately capture clinical data while ensuring the problem-centric orientation of clinical information that reflects the same procedures clinicians usually follow in practice.

3. Chronic Disease Management Model

The Western Health Infostructure Canada (WHIC) proposed a Chronic Disease Management (CDM) Model with the necessary data standards and the mapping of the HL7 messaging standard within this model. They also provided the implementation details of this infrastructure within participating jurisdictions in Canada (i.e., British Columbia, Alberta, Saskatchewan, and Manitoba) [2]. Although they [2] provided a general data model for CDM, the clinical data elements were chosen to focus mainly on three chronic diseases: diabetes, hypertension and chronic kidney disease. These were chosen by the participating jurisdictions.

WHIC adopted a person-focused, “Problem-Oriented Medical Record” approach to define this CDM model [3]. They provided the necessary options to record the problem-centric clinical actions (e.g., observations, procedures etc.), provider’s requests, planned actions, clinical goals and follow-ups. These are very crucial components for the successful management of chronic conditions. This model also tracks the accountability and responsibility of clinically qualified persons or organizations. This model has ontological representation with concepts, properties, and relationships between different concepts necessary for chronic disease management.

4. Computer-based Patient Record (CPR) Ontology

W3C first started to develop a Problem-Oriented Medical Record Ontology in 2006. The goal was to define a minimal set of healthcare information terms while ontologically grounding HL7 RIM as a process model and to use the criteria outlined in the traditional POMR structure [6]. This lead to the Web Ontology Language (OWL) based ontology in November 2009, called the Computer-based Patient Record (CPR) ontology [7]. Some parts of this ontology were taken from other top-level ontologies (e.g., BFO 1.1, BIOTOP, FMA etc.) to ensure a sound and coherent means of necessary terminological representations required by an EMR. The core concepts of this ontology are shown in Figure 1.

The top-level concepts of the CPR archetypes are shaded and shown with double circles in Figure 1. These are described below:

Clinical Acts: The most important concept of CPR ontology is ‘Clinical Acts’ which is used to model various clinical tasks and activities and the information flow within these activities. CPR used the process ontology of defining clinical processes as a workflow model proposed by Bayegan et. al. [19]. Its intention was to define the minimum number of clinical headings to facilitate effective clinical communication and documentation. These clinical headings were put under the ‘span: Process’ class of BFO Ontology [20] to ensure proper classification of occurants and continuants.

There are four specializations of Clinical Acts: Clinical Administration Act, Clinical Investigation Act, Procedure, and Therapeutic Act. A Clinical Administration Act is defined as any administrative act which is not itself investigatory or therapeutic and is done for either assessment or treatment (e.g., patient
A Clinical Investigation Act is used to discover the status, causes and mechanisms of a patient's health condition. A Procedure is a kind of act taken to improve the patient’s condition. This concept is used in this ontology to incorporate both diagnostic and therapeutic procedures and is aligned with the definition of Procedure in HL7 RIM.

Medical Problems: In this ontology, medical problems are defined as entities which incorporate the signs, symptoms and confirmed diseases of a patient. Signs are abnormalities interpreted by clinicians during physical examinations whereas symptoms are particular sensations reported by the patient themselves. The disease process has been defined as either pathological disease or etological agents while re-using the ontological framework for disease and diagnosis proposed by Scheuermann et.al. [21].

Findings: Findings are clinical examinations done by a clinical expert during an encounter to assess the condition of patient’s body parts.

Diagnosis: Diagnosis is not confirmed but hypothesized medical problem recorded during clinical analysis acts.

Informatics Artifacts: Informatics artifacts represent the pertinent information stored in an EMR. It includes all the clinical artifacts encountered in a patient, digital entities (e.g., diagnostic images), and other longitudinal information (e.g., clinical findings, symptoms). This concept is used to distinguish between the records of an action and the actual action itself.

Person: A person can be either the patient themselves or the clinically qualified person (e.g., nurse, general practitioner etc.).

Organ Components: Organ components are the anatomical and pathological entities those take part in different clinical procedures and screening acts.

The CPR ontology is engineered in Protégé using the OWL-DL language. Although it has all the necessary concepts an EMR should have, it lacks the properties of these concepts and the implementation of vocabulary binding in this ontology.

5. Ontology-based Electronic Medical Record for Chronic Disease Management

We have prototyped an ontology-based EMR which focuses on chronic disease management while providing a coherent information structure to support other acute diseases and co-morbidities. This EMR is
patient-centric by nature and holds the longitudinal information of patients. It facilitates coded data entry by using standard clinical vocabulary. We also map this ontology with HL7 RIM to ensure that the clinical messages in HL7 can be fully captured by this ontology.

POMR was chosen as the EMR standard to be used. The rationale of choosing POMR is that it captures and stores the clinical information in a problem-oriented way which is best suited for chronic disease management. The next step was to build an ontology on POMR. We reuse the CPR ontology [7] discussed in Section 4. The CPR is based on POMR. However, as discussed earlier, this ontology lacks the necessary properties (i.e., attributes) for holding data by its concepts. We create these properties in the CPR ontology by incorporating the core data elements proposed by ASTM-EHR [18] into the CPR. We mapped the concepts between the CPR ontology and ASTM-EHR for this purpose.

The next step was to map the WHIC proposed Chronic Disease Management Model [2] and the CPR ontology to ensure that the concepts and attributes necessary for chronic disease management are well supported by the resultant ontology, which we call EMR ontology. We converted the vocabulary proposed in the CDM model into SNOMED-CT since it provides a robust and powerful vocabulary in the clinical domain.

Finally, we mapped the resultant EMR ontology with HL7 RIM to ensure that the clinical messages in HL7 can be completely captured by the EMR ontology.

It is worth mentioning that the underlying model of ASTM-EHR, the CPR ontology and the CDM model used in these mapping procedures is POMR. The detailed mapping results are discussed below.

5.1. Mapping between ASTM-EHR and CPR

ASTM International defined 119 core attributes organized under fourteen entity segments which are necessary for any EHR information model [18]. We successfully incorporated these attributes as data type properties into the CPR ontology. This was done manually by mapping the ASTM-EHR entities onto the corresponding CPR ontology concepts. The mapping results are shown in Table 1.

We were able to map the ASTM-EHR entities and attributes into corresponding concepts of the CPR ontology. Direct mapping was possible in most of the cases. Some ASTM-EHR entities were mapped into more than one CPR ontology concept (e.g., Therapy/Procedures were mapped to two different concepts – Therapeutic Act and Procedure). In such cases, we manually divided the attributes of the ASTM-EHR entity and mapped these into the appropriate CPR ontology concepts. When we checked the mapping in the reverse direction (i.e., from the CPR ontology to the ASTM-EHR), we found that most of the concepts of the CPR ontology had the necessary properties for holding instances, with some exceptions (e.g., Clinical Administration Act, Clinical Analysis Act etc.).

<table>
<thead>
<tr>
<th>ASTM-EHR Entity</th>
<th>CPR Ontology Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient</td>
<td>Patient</td>
</tr>
<tr>
<td>Encounter/Episodes</td>
<td>Encounter</td>
</tr>
<tr>
<td>Referral</td>
<td>Referral</td>
</tr>
<tr>
<td>Problem</td>
<td>Medical-Problem</td>
</tr>
<tr>
<td>Provider/Practitioner</td>
<td>Provider, Practitioner</td>
</tr>
<tr>
<td>Care Order</td>
<td>Order</td>
</tr>
<tr>
<td>Treatment Plan</td>
<td>Planned Action</td>
</tr>
<tr>
<td>Immunization</td>
<td>Vaccination</td>
</tr>
<tr>
<td>Medication</td>
<td>Substance Administration</td>
</tr>
<tr>
<td>Therapy/Procedures</td>
<td>Therapeutic Act, Procedure</td>
</tr>
<tr>
<td>Operation</td>
<td>Medical Therapy</td>
</tr>
<tr>
<td>History</td>
<td>Screening Act</td>
</tr>
<tr>
<td>Assessment/Exams</td>
<td>Physical Examination</td>
</tr>
<tr>
<td>Diagnostic Tests</td>
<td>Diagnostic Procedure</td>
</tr>
</tbody>
</table>

5.2. Mapping between CPR ontology and the CDM model

Since, there are some differences between the information model of an EMR and the information model required for chronic disease management, a mapping scheme between these two is crucial. We mapped the CDM model onto the CPR ontology to make sure that our resultant EMR ontology contains all the necessary information elements required for successful chronic disease management.

We mapped these two standards at the concept level, the attribute level and the relationship level. For each concept in the CDM model, we checked whether it was available in the CPR ontology. We created one concept under the appropriate hierarchy in the CPR ontology if it was absent. We applied the same mapping procedures for both attributes and relationships. Some examples of these mapping results are shown in Tables 2-4 respectively.
Table 2: Examples of concept-level mapping between CDM and CPR ontology

<table>
<thead>
<tr>
<th>CDM Concept</th>
<th>CPR Ontology Concept</th>
</tr>
</thead>
<tbody>
<tr>
<td>Person</td>
<td>Patient</td>
</tr>
<tr>
<td>Referral</td>
<td>Referral</td>
</tr>
<tr>
<td>Procedure</td>
<td>therapeuticAct U procedure</td>
</tr>
<tr>
<td>Chronic Condition</td>
<td>medical-problem</td>
</tr>
<tr>
<td>CarePlan</td>
<td>PlannedAct</td>
</tr>
<tr>
<td>Observations</td>
<td>screening-act U diagnostic-procedure U clinical-finding</td>
</tr>
</tbody>
</table>

Table 3: Examples of attribute-level mapping between CDM and CPR ontology

<table>
<thead>
<tr>
<th>CDM Attribute</th>
<th>CPR Ontology Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observation</td>
<td>Diagnosticprocedure.Numeric MeasurementOr AnalyteInterpretation, clinical-examination, ExamFindings, medical-history-screening-act, clinical-finding.value</td>
</tr>
<tr>
<td>Goal type</td>
<td>goalType</td>
</tr>
<tr>
<td>Goal value</td>
<td>goalValue</td>
</tr>
<tr>
<td>Planned procedure type</td>
<td>Planned-Procedure.procedureType</td>
</tr>
<tr>
<td>Observation normal range value</td>
<td>diagnostic-procedure.normalRangeValue</td>
</tr>
</tbody>
</table>

Table 4: Examples of relationship-level mapping between CDM and CPR ontology

<table>
<thead>
<tr>
<th>Relationship</th>
<th>Domain</th>
<th>Range</th>
<th>Relationship</th>
<th>Domain</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>appliesTo (funct)</td>
<td>CDM Record</td>
<td>Person</td>
<td>AppliesToPatient</td>
<td>patient-record</td>
<td>Patient</td>
</tr>
<tr>
<td>has (reqd.)</td>
<td>Care Plans</td>
<td>Goals</td>
<td>contains</td>
<td>PlannedAct</td>
<td>Goal</td>
</tr>
</tbody>
</table>

Figure 2: Core concepts of the resultant EMR ontology.
It was observed that the CPR ontology lacked some very crucial concepts for chronic disease management (e.g., care plans, goals, referrals etc.). We created these concepts under the appropriate hierarchy. Some concepts were found in both the CDM model and the CPR ontology (e.g., patient, practitioner, procedure, diagnostic act etc.). Similar observations were found for the attribute-level and the relationship-level mappings. Out of 26 concepts, 82 attributes and 17 relationships of the CDM model, we had to create 8 new concepts, 37 new data-type properties and 13 new object properties in the CPR ontology.

After all of these mappings, we found the resultant EMR ontology which is shown in Figure 2. We introduced a new concept, ‘Encounter’, into this ontology which, we believe, is very important to keep track of the follow-ups and long term care plans. As shown in Figure 2, we classified clinical actions into two main categories: clinical acts (which incorporates the actual acts being undertaken for a patient), and planned acts (the actions planned for successful chronic disease management).

We also ensured a structured way of data entry by using the codes described in CDM [5]. We transformed all the codes of CDM [5] into SNOMED-CT and integrated these into our EMR ontology. We constructed a top-level class ‘Vocabulary’ which contains all the code table entities with two properties: concept name (i.e., the concept name for this entity in SNOMED-CT), and code (i.e., the exact code in SNOMED-CT for this concept).

### 5.3. Mapping between EMR ontology and HL7 RIM

The next step was to map the resultant EMR ontology with HL7 RIM. Since WHIC already mapped their proposed CDM model with HL7 [4], we had to map the additional concepts and properties used in the EMR ontology with HL7 RIM. The mapping procedure was done manually by choosing the closest possible concept (or property) of HL7 RIM for each concept (or property) of the EMR ontology. Examples of such mapping results are shown in Table 5.

We found that all of the concepts of the EMR ontology were successfully mapped into corresponding concepts of HL7 RIM. Out of 80 properties of the EMR ontology, 8 were partially mapped (e.g., PatientPermanentAddress) and 10 could not be mapped (e.g., Physician.UniversalIDNumber) to HL7 RIM.

Since HL7 RIM provides a very robust information model to capture the clinical data from almost every aspect, we devised a smaller refined model of it, based on the mapping results. We found such a subset of HL7 RIM, which is shown in Figure 3.

### Table 5: Examples of Mapping results between EMR Ontology and HL7 RIM

<table>
<thead>
<tr>
<th>EMR Ontology Property</th>
<th>HL7 RIM Attribute</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clinical Examination</td>
<td>Observation (with Act.classCode= 'Physical Examination' and ActCode= 'CommonClinical ObservationType') /LOINC Code 11384-5</td>
</tr>
<tr>
<td></td>
<td>DateTimeOfExam</td>
</tr>
<tr>
<td></td>
<td>ExamFindings</td>
</tr>
<tr>
<td></td>
<td>ExamSummary</td>
</tr>
<tr>
<td></td>
<td>Diagnostic Procedure</td>
</tr>
<tr>
<td></td>
<td>Numeric MeasurementOr AnalyteName</td>
</tr>
<tr>
<td></td>
<td>Numeric MeasurementOr AnalyteValue</td>
</tr>
<tr>
<td></td>
<td>medical-problem</td>
</tr>
<tr>
<td></td>
<td>ProblemCurrentStatus</td>
</tr>
<tr>
<td></td>
<td>ProblemDateOfOnset</td>
</tr>
<tr>
<td></td>
<td>ProblemName</td>
</tr>
</tbody>
</table>

All the clinical actions of the proposed ontology were found to map to the RIM classes, Observation and Procedure. ActHeir class has been chosen to satisfy the condition that an Act can have another Act as part of it. The act codes have been used to represent the concepts such as planned actions (with moodcode=’Goal’), medical problems (with code=’Condition’) etc. of this ontology. The Person class of RIM maps with both Patient (with role Patient) and Practitioner (with role Employee) of the proposed Ontology. Device class has been chosen to map with the anatomical and pathological entities whereas ManufacturedMaterial represents Medication and Vaccination of the proposed ontology with role Access. ActRelationship and Participation are core classes of RIM being used to link between different Acts, and to define the particular actions an Entity is playing within a particular Role.
6. Results

6.1. Evaluation for compliance with standard design principles of ontology

We manually checked the compliance of our proposed EMR ontology against two sets of standard design principles: Gomez-Perez's ontology design principles [23] and Bodenreider's design principles [24]. While the design principles proposed by Gomez-Perez [23] are a bit more theory-oriented and abstract, the ones proposed by Bodenreider [24] are more development-oriented. We found that our proposed EMR ontology satisfies the basic principles of Gomez-Perez [23]. Among the design principles proposed by Bodenreider [24], some were already enforced by Protégé. We examined the rest and found that the criteria ‘Non-leaf classes must have at least two children’ was partially satisfied by our ontology with some exceptions (e.g., the Procedure class has only one child, Referral).

6.2. Instantiations of the proposed EMR ontology

We instantiated the proposed ontology with two different medical records, both written in HL7: one was proposed by WHIC as a Sample Record Notification Message [25], and the other one was used as an example in the ‘HL7 Implementation Guide for Continuity of Care Document’ [26]. An example of the instantiation for [25] has been shown in Figure 4.

The WHIC proposed sample HL7 message was successfully instantiated into our EMR ontology. This is justified since we are using the proposed CDM model as an underlying mapping model in our proposed methodology. However, the instantiation of the example medical record for the HL7 Continuity of Care Record [26] was particularly interesting because of the need to evaluate whether the proposed ontology can capture the medical records of some other formats. The instantiation results for this record are summarized in Table 6, found at the end of the paper.

As shown in Table 6, we observed that most of the concepts of the example were successfully instantiated into our proposed ontology. However, we encountered that the medication or immunization status (e.g., Active) could not be captured into our ontology. We could also encode most of the clinical terms with a few exceptions (e.g., the diagnostic procedure, HCO3).
7. Conclusion

We have prototyped a patient-centric, longitudinal Electronic Medical Record ontology focusing mainly on chronic disease management. Since the ontology is based on the POMR information model, it can also be used for the treatment of other acute diseases. This ontology ensures structured data entry by using SNOMED-CT controlled vocabulary codes and we have successfully mapped the proposed ontology onto HL7 RIM to ensure that clinical messages would be successfully captured by this ontology. As the ontology is implemented in OWL-DL, decision support systems can be implemented through reasoning over the Description Logic (DL) representation. The evaluation results show that our proposed ontology can capture the elements of clinical records and has the capability of representing the knowledge on a patient’s medical records.

While mapping with HL7 RIM, we have observed some differences between it and our proposed ontology from an ontological point of view. For example, the proposed ontology differentiates between continuants and occurrants, whereas HL7 RIM does not. We realize that some further technical implementations are necessary to reason over HL7 messages automatically and to fit RIM entities into appropriate concepts (e.g., Observation of HL7 RIM into clinical-examination, diagnostic-procedure etc.). WHIC provided code tables focus mainly on three chronic diseases and we use the SNOMED-CT codes for their code tables. However, we believe that our proposed ontology is flexible enough to incorporate new coded elements for other chronic diseases.

The research reported in this paper is part of a larger project to create clinical decision support systems for chronic diseases, instantiated by EMRs. Our EMR ontology will not only support this project but can also be used as a switching language among various EMR standards.

8. Acknowledgement

This research was funded in part by the Green Shield Canada Foundation.

9. References

Table 6: Instantiation results for example of HL7 CCD [26]

<table>
<thead>
<tr>
<th>HL7 CCD Attribute</th>
<th>EMR Ontology Property</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problems.Condition</td>
<td>Medical-problem.proBLEMNAME</td>
</tr>
<tr>
<td>Problems.EffectiveDates</td>
<td>Medical-problem.dateofOnset</td>
</tr>
<tr>
<td>Problems.ConditionStatus</td>
<td>Medical-problem.status</td>
</tr>
<tr>
<td>Family History</td>
<td>Screening-act.observationType='Family History'</td>
</tr>
<tr>
<td>Social history</td>
<td>Screening-act.observationType='Social History'</td>
</tr>
<tr>
<td>Allergies and Adverse Reactions</td>
<td>Screening-act.observationType='Allergy Alert' and 'Adverse Drug Reaction'</td>
</tr>
<tr>
<td>Medications.Medication</td>
<td>Substance-administration.medicationName</td>
</tr>
<tr>
<td>Medications.Instruction</td>
<td>Substance-administration.medicationInstructions</td>
</tr>
<tr>
<td>Medications.StartDate</td>
<td>Substance-administration.MedicationOrVaccineDate</td>
</tr>
<tr>
<td>Medications.Status</td>
<td>-</td>
</tr>
<tr>
<td>MedicalEquipment with supply date</td>
<td>Material entity</td>
</tr>
<tr>
<td>Immunizations.Vaccine</td>
<td>Substance-administration.MedicationOrVaccineName</td>
</tr>
<tr>
<td>Immunizations.Date</td>
<td>Substance-administration.MedicationOrVaccineDate</td>
</tr>
<tr>
<td>Immunizations.Status</td>
<td>-</td>
</tr>
<tr>
<td>Vital Signs with date time</td>
<td>Vital Signs with clinical-examination.date</td>
</tr>
<tr>
<td>Results with date time</td>
<td>Diagnostic-procedure with date</td>
</tr>
<tr>
<td>Procedures with date time</td>
<td>Procedure with date</td>
</tr>
<tr>
<td>Encounters with location and date time</td>
<td>Encounter with date and Provider.location</td>
</tr>
<tr>
<td>Care Plan with date</td>
<td>PlannedAct with reassessment date</td>
</tr>
</tbody>
</table>