Crafting Electronic Medical Record Ontology for Interoperability

Esingbemi Princewill Ebietomere  
*University of Benin, Benin City, princewill.ebietomere@uniben.edu*

Ukeme Nse  
*University of Benin, Benin City, nse.ukeme@physci.uniben.edu*

Betty Ukhuegbe Ekuobase  
*University of Benin Teaching Hospital, Benin City, ekuobasebetty@gmail.com*

Godspower Osaretin Ekuobase  
*University of Benin, Benin City, godspower.ekuobase@uniben.edu*

Follow this and additional works at: [https://digitalcommons.kennesaw.edu/ajis](https://digitalcommons.kennesaw.edu/ajis)

Part of the Management Information Systems Commons

**Recommended Citation**

Available at: [https://digitalcommons.kennesaw.edu/ajis/vol13/iss3/2](https://digitalcommons.kennesaw.edu/ajis/vol13/iss3/2)
Crafting Electronic Medical Record Ontology for Interoperability

Cover Page Footnote
The authors wish to acknowledge the Head of Medical Records Unit of the University of Benin Teaching Hospital, Benin City for providing the required Medical information and records used in this research.

This article is available in The African Journal of Information Systems: https://digitalcommons.kennesaw.edu/ajis/vol13/iss3/2
ABSTRACT
Clinical information system (CIS) whose core component is the electronic medical record (EMR), is critical to efficient health care delivery. However, patient mobility and CIS heterogeneity have strengthened the interoperability problem of EMRs. Although ontology is a panacea to this problem, creating interoperable EMR ontology is still esoteric. This paper explicates how an interoperable EMR ontology was crafted for a tertiary health facility in Nigeria. The ontology named EMRONT was created using the Noy and McGuiness’ methodology and Protégé. EMRONT has been evaluated for quality using competency questions and OntoQA and subsequently refined for interoperability by manual mapping to both Health Level 7 (HL7) standard and SNOMED-CT. EMRONT has been further refined for interoperability by semi-automatic mapping to SNOMED-CT using Snoggle. This paper has made exoteric the hitherto esoteric craft of building interoperable EMR ontology and exposed how semi-automatic mapping of EMR ontology to SNOMED is done in practice.

Keywords
Electronic medical record, ontology, ontology mapping, HL7, SNOMED-CT, interoperability.

INTRODUCTION
The healthcare system is responsible for the provision of health care to patients. At the heart of caring for patients is clinical information system (CIS) with electronic medical record (EMR) as its core component (Iqbal, 2011; Waggott et al., 2016). Many health facilities particularly in the developing countries, still manage patients using manual medical record (MMR). Although MMR is grossly inefficient, unreliable, and unsustainable (Hoffmann, 2009; Iqbal, 2011; World Health Organization, 2006), the alternate, EMR, is also capable of stifling efficient health care delivery because of
interoperability problem (Berzell, 2010; Hoffmann, 2009; Koopman et al., 2011). This problem of interoperability is further complicated by patient mobility (Al-Safadi, 2008), heterogenous medical personnel, medical information, CISs, and EMRs (Call, 2013; Hoffmann, 2009; Kambiz et al., 2003; World Health Organization, 2006).

A solution to this problem is a structured and common vocabulary or conceptualization across all health facilities in the globe (Azarm & Peyton, 2018; Call, 2013). This solution though daunting is feasible via ontology and other semantic technologies (Azarm & Peyton, 2018; Berzell, 2010; Ebietomere & Ekuobase, 2019; Ekuobase & Ebietomere, 2016; Sachdeva & Bhalla, 2012). The reality however is that it is impossible to have a single EMR ontology (Berzell, 2010) considering differences in culture across health facilities (Azarm & Peyton, 2018; Hoffmann, 2009). It is therefore imperative to have EMR ontology built in line with the culture of each health facility to avoid rejection of the resultant technology. This however will lead to proliferation of EMR ontologies which will result in confusion among health personnel in delivering health care to patients across health facilities.

Unfortunately, of the few works that have built EMR ontology (Al-Safadi, 2008; Azarm & Peyton, 2018; Call, 2013; DePalo et al., 2014; El-Atawy & Khalefa, 2016; Iqbal, 2011; Limspatham et al., 2013), those tailored towards solving the problem of interoperability (Al-Safadi, 2008; Azarm & Peyton, 2018; DePalo et al., 2014; El-Atawy & Khalefa 2016; Iqbal, 2011) have dearth exposure of how to create interoperable EMR ontology. The consequence of this is dire as it will exacerbate the scarcity of ontology engineers and the execrable health care delivery in Africa even with increasing knowledge and competency of health personnel in the continent.

Related Works

Al-Safadi (2008) proposed an ontology-based system named MREx – medical record exchanger. The system allows health care facilities with EMRs to share real-time medical information on demand in a distributed and semantic heterogeneous environment. The author leveraged on an existing ontology (practice, drug, diagnosis/procedure ontologies) and did not expose how the ontology aligns with standards to ensure interoperability.

Iqbal (2011) realized a problem oriented medical record (POMR) based EMR ontology. The work reused an existing computer-based patient record (CPR) ontology which was then mapped to both Health Level (HL7) and Systemized Nomenclature for Medicine (SNOMED) to achieve interoperability. However, apart from the fact that Iqbal (2011) focused only on chronic disease management, it suggested the possibility of a semi-automatic mapping tool producing a more reliable interoperability than manual mapping to SNOMED. This suggestion has been explored as Harrow et al. (2019) affirmed that employing the semi-automatic mapping to SNOMED yields better interoperable EMR ontology but how to do this is repressed in literature.

Limsopatham et al. (2013) employed an ontology-based approach to improving medical records search through concepts relationship inference. The purpose of the ontology was for improved retrieval of EMR and did not concern itself with interoperability of EMR ontology.

DePalo et al. (2014) employed an ontology-based approach towards improving patient health care in transport medicine. The purpose of the ontology was to ease the difficulty associated with accessing and sharing EMR. However, apart from the fact that the work did not expose how the ontology was built, it also did not give a description of how it was aligned with standards to ensure interoperability.

El-Atawy and Khalefa (2016) proposed an ontology approach for building EMR system. Their emphasis was on decoupling large code base that is usually associated with EMR systems from their data model to
ease maintenance which they argued will reduce cost. They posited that ontology-based approach would help achieve this goal. The work however did not expose the constructed ontology and how it was aligned to it purpose.

Azarm and Peyton (2018) proposed an ontology-based framework that can provide a secure single point of access to personal health information. The purpose of the ontology which they built from scratch was to aid retrieval and interoperability. Though the HL7 standard was followed in the construction of the ontology, the interoperability capability of the ontology was not determined or exposed.

The dearth exposure of how to create interoperable EMR ontology is therefore evident. This paper explicates how an EMR ontology called EMRONT was crafted from scratch and refined for interoperability using a semi-automatic mapping tool in addition to the manual approaches. Also exposed is how EMRONT was evaluated for quality as quality equivalence is an attribute of interoperable EMR ontology.

The remaining part of this paper is organized as follows; first, background information for improved cognition of the paper is provided. This is immediately followed by details on how the ontology was constructed and evaluated. Thereafter, details of the craft of refining the built EMR ontology for interoperability are presented. Finally, the conclusion is presented.

BACKGROUND INFORMATION

Medical Records

The practice of providing health care services and keeping medical records dates to the 10th century among the Mesopotamians, Egyptians, Indians, Chinese, and Greeks. In the quest to preserve their medical knowledge they documented their medical experiment, observation, and procedure on paper. Among these early medical practitioners, the Mesopotamians and the Greek kept not just the records for medical procedures but also the record of every patient that was treated. While the Mesopotamians’ records consist of the patient mental health information with meaning assigned to it, the Greek’s medical records consist of the names, case histories, complaints, and causes. These records serve as references consisting of domain knowledge used by health care personnel in making vital medical decisions; hence, the importance of keeping such records cannot be overstressed (Hoffmann, 2009).

The term Medical Record (MR) is often used interchangeably with Health Record (HR) or Patient Health Record (PHR). Several definitions exist in literature as to what MR is and its content (Haux, 2006; World Health Organization, 2006). Notable among the definitions are that of Haux (2006) and Durking (2006). Haux (2006, as cited in Garba and Harande, 2018) stated that MR is a “documented information about the health of an identifiable individual recorded by a practitioner or other healthcare professional, either personally or at his or her instructions” (p. 27). Durking (2006, as cited in Garba and Harande, 2018) described MR to include items such as “Patient History, and Examination report, Consultation report, Operative report, Radiology report, Pathology report, Laboratory report, Emergency report, SOAP note report (Subjective, Objective, Assessment and Plan notes), Progress note report, Therapy report, Clinical notes, Autopsy report, Biopsy report, Psychiatric observations, X-ray report, Scan report, Referral letters, Daily report” (pp. 27–28).

If MR is handled using electronic means, it is then referred to as EMR or Electronic Health Record (EHR). Though there are arguments as to the difference between EMR and EHR, this paper treats them as synonyms. In recent times, there is a proliferation of EMR systems, a trend that will continue because of the huge benefits of EMRs to healthcare delivery (Call, 2013; Hoffmann, 2009; Koopman et al.,
2011). Conversely, EMR systems have their challenges that include inefficient retrieval (Call, 2013; Koopman et al., 2011) and poor interoperability (Sachdeva & Bhalla, 2012; Berzell, 2010; Hoffmann, 2009).

**EMR Retrieval**

Retrieval is a critical activity of CISs because there is always a reason to source for a whole or part of records associated with patients for ease of continuous care. Retrieving such records about patients is not as easy as it seems, as the type of retrieval system employed determines how efficient the CIS would be. Search using keywords seem to be very prevalent but bedeviled by inaccurate retrieval of records because of the lacuna that exists between the user (patient and health care personnel) query and the information repository, particularly with increasing population and complexity of a CIS. Ontology has been touted as a panacea to the problem of inefficient retrieval of information including EMR. The efficacy of ontology for efficient retrieval of information has been established in several domains including healthcare (Call, 2013; Ebietomere & Ekuobase, 2019; Koopman et al., 2011); and thus, this paper will not concern itself with EMR retrieval problem.

**EMR Interoperability**

For seamless exchange of information and ease of collaboration among health personnel, there is need for the interoperability of CISs. In nursing informatics, the term semantic interoperability is preferred. Several definitions exist for semantic interoperability; and notable among these definitions are those given by the National Health Information Network (NHIN) and IEEE Standard 1073. The IEEE-USA Medical Technology Policy Committee Interoperability Working Group (2005, as cited in Sachdeva and Bhalla, 2012) describes semantic interoperability as “the ability to interpret, and, therefore, to make effective use of the information so exchanged” (p.5). Sachdeva and Bhalla (2012) also stated that “IEEE Standard 1073 defines semantic interoperability as shared data types, shared terminologies, and shared coding” (p.5). From the definitions, the following are evident; (a) the information sent within and across CISs must be such that is interpretable by the receiving system for communication to be established, and (b) the need to establish a common vocabulary within and across CISs. Standards such as the open EHR, Logical Observation Identifiers Names and Codes (LOINC) and HL7 have been established to leverage information exchange (Sachdeva & Bhalla, 2012).

In this paper, the HL7 standard model (Iqbal, 2011) was employed to refine the constructed EMR ontology, EMRON, for interoperability because of its popularity (Al-Safadi, 2008, Azarm & Peyton, 2018). The components of the model are highlighted as follows (Iqbal, 2011):

- **Entity:** this represents a given physical object or thing (e.g. record, person, place).
- **Role:** this is a function performed by an entity (e.g. patient, employee, licensed entity).
- **Act:** specifies all actions and events of health care services, the action may be on going, about to or has been performed (registration, diagnosis, document).
- **Participation:** expresses the entire make up for an act such as who performed it, for whom it was executed, where it was performed (e.g. author, subject, performer).
- **ActRelationship:** this relates an Act to another (e.g. support, composition).
- **RoleLink:** this expresses the relationship between roles.

More so, in establishing common vocabulary across heterogeneous CISs, some standards such as Systemized Nomenclature for Medicine-Clinical Term (SNOMED-CT) and International Classification
of Disease (ICD) are already in place though none has been found to be self-sufficient. In this paper, EMRONRT was further refined for interoperability by mapping it to SNOMED-CT. The reason for opting for SNOMED-CT is because it has been adjudged the most elaborate among its kind.

**Ontology**

There are several definitions adduced to ontology in literature (Ebietomere, 2018; Ekuobase & Ebietomere, 2016) but this work sees ontology from the perspective of Noy and McGuiness (2001), which defines ontology as a “formal explicit description of concepts in a domain of discourse (classes), properties of each concept describing various features and attributes of the concept (slots) and restrictions on the slots (facets)” (p. 3). Ontologies are created for several reasons which include: (a) sharing common understanding of information structure among entities; (b) to enable reusability of domain knowledge; (c) to make domain assumptions unambiguous; (d) to distinguish domain knowledge from operational knowledge and (e) analyze domain knowledge (Azarm & Peyton, 2018; Ekuobase & Ebietomere, 2016). While database stores data, ontology stores knowledge – data with meaning (Ekuobase, 2020). The following section details how EMRONRT was created and evaluated for quality.

**MATERIALS AND METHOD**

EMRONRT was created from scratch because as with most developing countries MRs of health facilities are hugely paper based. Our case study facility – the University of Benin Teaching Hospital, Benin City (UBTH) – a foremost and notable tertiary health facility in Nigeria was not different with only a small portion of its MRs in electronic form. The implementation process to realize EMRONRT is captured in Figure 1. Specifically, the Noy and McGuiness’ methodology (Noy & McGuiness, 2001) was employed from among other several methodologies (Ebietomere, 2018; Ekuobase & Ebietomere, 2016; Sanchez, 2009) to create EMRONRT. The choice of Noy and McGuiness’ methodology is premised on its simplicity and flexibility. Besides, the methodology has been successful for crafting ontology as evident in Azarm and Peyton (2018), Ekuobase and Ebietomere (2016) and Ekuobase and Ebietomere (2013).

As evident in Figure 1, a list of clinical concepts was elicited from the MR samples and other clinical documents obtained from the MRs unit of UBTH by stepwise refinement. This was after a detailed study of the clinical documents to understand the constituents and structure of the clinical concepts contained therein. The ontology built was subjected to consistency check and then queried to determine correctness using a set of formulated competency questions. The ontology was then evaluated for quality using OntoQA and thereafter mapped to standard reference ontologies and step-wisely refined for interoperability, manually using HL7 and SNOMED-CT and semi-automatically using SNOMED-CT with Snoggle.
Figure 1
Crafting an EMRs Ontology for Interoperability

EMRONT Creation
Building ontology with the Noy and McGuiness’ methodology involves the following steps:
1. Determining the scope and domain of the ontology.
2. Consider reusing an existing ontology.
3. Make a list of necessary terminologies for the ontology domain.
4. Define and organize into hierarchy—the classes for the ontology.
5. Outline the properties associated with the defined classes.
6. Outline the data types associated with properties defined.
7. Create instances for the defined classes (Noy & McGuiness, 2001).

More so, to maintain the focus of EMRONT as strictly an EMR ontology, the following competency questions were designed to define its scope and determine its alignment with its purpose:
- a listing of all patients and their personal information
- the record of a specific patient
- the previous diagnosis of a specific patient
- the list of drugs prescribed to a patient
- medical procedure(s) performed on a patient
- a specific patient’s allergies
- who treated a patient
- a list of medical facility a patient has been to and what treatment was given
- what therapy was given to a patient
With these competency questions in mind, the seven steps of the Noy and McGuinness’ methodology were judiciously followed to birth EMRONT. The class design of EMRONT is depicted in Figure 2.

**Figure 2**

*Class Design of EMRONT*

As in Figure 2, classes in the ontology include Patient, Person, Record staff, Doctor, Record and Hospital; while the relations include prescribes, treats, creates, writes, and performs. It is obvious from the diagram that a relation connects one class to another. For example, the class Record and Record staff are connected by the relation “creates”, thus, we could have phrases like: Record staff creates a Record, or a Record is created by Record staff. From preceding sentence, it is obvious that the latter phrase is the inverse of the former phrase.

To implement the design, Protégé 4.3 beta editor was employed due to its popularity, ease of use, compatibility with RDF and OWL, interoperability, and rich library of plug-ins. FACT++ and HermiT 1.3.8 plug-ins were used for reasoning, and consistency checks. Thereafter, OWLViz and ontoGraf were used to visualize EMRONT. Some of the visualizations of EMRONT are shown in Figures 3 to 5.

As in Figure 3, every ontology in Protégé starts from the root class, “Thing”. The immediate level of classes subsumed by the class Thing include “IdentityMode”, and “MedicalEntity” and those subsumed by MedicalEntity include “Hospital”, “MedicalNote”, “Patient” and “Record”. The subclasses of MedicalNote include “AdmissionNote”, “DrugRecordNote” and “DentalNote” with the Record class subsuming such classes like “CardiologyRecord”, “HematologyRecord” and “SurgeryRecord”. Also, some of the properties defined in EMRONT are shown in Figure 4a and Figure 4b.
Figure 3

An Excerpt of the Hierarchical View of Some of the Classes in EMRONT

![Hierarchical view of classes in EMRONT ontology](image)

Figure 4a

Excerpt of Object Properties in EMRONT

```
- topObjectProperty
  - belongTo
  - contains
  - creates_a
  - diagnosis
  - has
  - has_a
  - in_part_ofPreopt
  - is
  - is_consultant_in
  - is_contain_in
  - is_create_by
  - is_part_of
  - is_perform_by
  - is_read_by
  - is_specialist
  - is_written_to_by
  - performs
  - reads_a
  - treat
  - urologyrecordhas
  - writes_to
```
Figure 4b
Excerpt of Data Properties in EMRONT

Figure 4a shows some object properties of EMRONT while some of the data properties are shown in Figure 4b. The grid view of EMRONT is presented in Figure 5.

Figure 5
EMRONT Grid View
The rectangles with small oval shape in yellow color at its top left denote the classes in the ontology and the lines in the diagram show the relations among the classes. In addition, the classes with “+” at the top left of its rectangle are indications that they have subclasses which are however hidden in Figure 5.

**EMRON’T Evaluation**

After creating EMRON’T, the next step was evaluation. The ontology was evaluated to assess its relevance and quality both from the developer and the user perspectives. For the developers, it will expose areas of the ontology that needs improvement and for the users, it will expose areas in the ontology that may give problems and allow the users compare EMRON’T with other ontologies to ease the process of choosing the most appropriate for their application. There are different approaches, techniques and tools used for evaluating and validating ontologies (McDaniel & Storey, 2019; Noy & McGuinness, 2001; Raad & Cruz, 2015; Surendro et al., 2020; Tartir et al., 2007). In this work, apart from carrying out consistency check on the built ontology, a set of competency questions was designed to determine the correctness of EMRON’T. OntoQA (a feature-based ontology evaluation method) was adopted to expose the ontology design and potential for rich knowledge representation. The evaluation procedures are discussed as follows.

**Evaluating EMRON’T for Correctness**

To expose the correctness of EMRON’T, it was queried using the set of competency questions designed and launched in SPARQL. SPARQL is a recursive acronym for “SPARQL Protocol and RDF Query Language” – a W3C standard query language. The results from some of the queries launched in SPARQL are captured in Tables 1 to 5.

**Query1:** a list of patients and their personal information.

```sparql
WHERE{
?pin phront:is_a ?patient.
?Personalinformation phront:patientID ?pid
}
```

**Table 1**

*Result Returned for Query1*

<table>
<thead>
<tr>
<th>pin</th>
<th>patient</th>
<th>Personalinformation</th>
<th>age</th>
<th>dob</th>
<th>address</th>
<th>occ</th>
<th>gender</th>
<th>name</th>
<th>pid</th>
<th>Record</th>
</tr>
</thead>
<tbody>
<tr>
<td>ph102</td>
<td>deiptpatient1</td>
<td>peminfo11</td>
<td>&quot;60&quot;</td>
<td>&quot;<a href="http://www/2/12/9/92">http://www/2/12/9/92</a>&quot;</td>
<td>&quot;<a href="http://www/2/12/9/92">http://www/2/12/9/92</a>&quot;</td>
<td>&quot;<a href="http://www/2/12/9/92">http://www/2/12/9/92</a>&quot;</td>
<td>&quot;<a href="http://www/2/12/9/92">http://www/2/12/9/92</a>&quot;</td>
<td>&quot;<a href="http://www/2/12/9/92">http://www/2/12/9/92</a>&quot;</td>
<td>&quot;<a href="http://www/2/12/9/92">http://www/2/12/9/92</a>&quot;</td>
<td>&quot;<a href="http://www/2/12/9/92">http://www/2/12/9/92</a>&quot;</td>
</tr>
<tr>
<td>ph102</td>
<td>deiptpatient1</td>
<td>peminfo11</td>
<td>&quot;60&quot;</td>
<td>&quot;<a href="http://www/2/12/9/92">http://www/2/12/9/92</a>&quot;</td>
<td>&quot;<a href="http://www/2/12/9/92">http://www/2/12/9/92</a>&quot;</td>
<td>&quot;<a href="http://www/2/12/9/92">http://www/2/12/9/92</a>&quot;</td>
<td>&quot;<a href="http://www/2/12/9/92">http://www/2/12/9/92</a>&quot;</td>
<td>&quot;<a href="http://www/2/12/9/92">http://www/2/12/9/92</a>&quot;</td>
<td>&quot;<a href="http://www/2/12/9/92">http://www/2/12/9/92</a>&quot;</td>
<td>&quot;<a href="http://www/2/12/9/92">http://www/2/12/9/92</a>&quot;</td>
</tr>
</tbody>
</table>

**Query2:** the record belonging to a specific patient.

```sparql
WHERE{

...

```
?pin phront:is_a ?patient.

Table 2

Result Returned for Query2

<table>
<thead>
<tr>
<th>pin</th>
<th>patient</th>
<th>PersonalInformation</th>
<th>age</th>
<th>dob</th>
<th>address</th>
<th>scc</th>
<th>gendar</th>
<th>name</th>
<th>pid</th>
</tr>
</thead>
<tbody>
<tr>
<td>p101</td>
<td>cdp11</td>
<td>p102</td>
<td>26</td>
<td>1992</td>
<td>0001</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Query3, Query4 and Query5: the previous diagnosis of a specific patient, the list of drugs prescribed to the patient, and medical procedure(s) performed on the patient.

?pin phront:is_a ?patient.
?patient phront:has_a ?PersonalInformation.
?PersonalInformation phront:Name ?n.
?patient phront:has_a ?r.
?mn phront:drugeName ?dg.
?mn phront:date ?date.
}

Table 3

Result Returned for Queries 3, 4, and 5

<table>
<thead>
<tr>
<th>pin</th>
<th>patient</th>
<th>PersonalInformation</th>
<th>r</th>
<th>mn</th>
<th>pid</th>
<th>p</th>
<th>o</th>
<th>t</th>
<th>n</th>
<th>d</th>
<th>pin1</th>
<th>date</th>
</tr>
</thead>
<tbody>
<tr>
<td>p101</td>
<td>cdp11</td>
<td>p102</td>
<td>cardio11</td>
<td>cardinote</td>
<td>&quot;100&quot;</td>
<td>&quot;chest pain&quot;</td>
<td>&quot;surgery&quot;</td>
<td>&quot;16/5/2019&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>p101</td>
<td>cdp11</td>
<td>p102</td>
<td>cardinotex</td>
<td>&quot;100&quot;</td>
<td>&quot;heart ECG fail&quot;</td>
<td>&quot;surgery&quot;</td>
<td>&quot;6/7/2019&quot;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Query6: a specific patient’s allergies.

?pin phront:is_a ?patient.
?patient phront:has_a ?PersonInformation.
?PersonInformation phront:Name ?n.
?patient phront:is_alergic_to ?alergic_to.
}
 Query7: who treated a patient?

```
WHERE{
  ?doc phront:has_a ?StaffBioInformation.
  ?StaffBioInformation phront:staff_name ?docname.
  ?Patient phront:has_a ?PersonInformation.
  ?PersonInformation phront:Name ?n.
}
```

Table 5

Result Returned for Query7

<table>
<thead>
<tr>
<th>pin</th>
<th>Patient</th>
<th>PersonInformation</th>
<th>r</th>
<th>mn</th>
<th>pid</th>
<th>p</th>
<th>o</th>
<th>docname</th>
<th>n</th>
<th>d</th>
<th>pin1</th>
<th>doc</th>
</tr>
</thead>
<tbody>
<tr>
<td>ph101</td>
<td>cdp11</td>
<td>p102</td>
<td>&quot;100&quot;^^&lt;<a href="http://www.w">http://www.w</a></td>
<td></td>
<td>&quot;Er</td>
<td>thom</td>
<td></td>
<td>Umke</td>
<td></td>
<td>&quot;eric</td>
<td></td>
<td>ericT</td>
</tr>
</tbody>
</table>

The results from the queries were correct and as expected. Thus, EMRON T is clearly in alignment with its ontological commitments of supplying patient medical records in part or whole.

**EMRON T Evaluation using OntoQA**

The created ontology was loaded into the OntoQA via its interface and the result obtained after selecting the “Calculate Metrics” tab is as shown in Figure 6.

From Figure 6, it is obvious that there are two basic categories of ontology metrics, namely schema and knowledgebase metrics. The formula for the computation of each of these metrics is given in Equations 1 to 5 (Tartir et al., 2005):

Relationship Richness (RR):

\[
RR = \frac{|P|}{|SC|+|P|} ;
\]  
(1)

Where \( P \) is the number of relationships defined in the schema, and \(|SC|\) is the sum of number of subclasses.

Inheritance Richness (IR):

\[
IR = \frac{\sum_{C_i \in C} |H^C(C_i,C_i)|}{|C|} ;
\]  
(2)

Where \(|H^C(C_i,C_i)|\) is the number of subclasses \((C_i)\) for a class \(C_i\).
Attribute Richness (AR):

\[ AR = \frac{|\text{att}|}{|\mathcal{C}|}; \]  

(3)

Where \( |\text{att}| \) is the number of attributes for all classes and \( |\mathcal{C}| \) is the number classes.

Class Richness (CR):

\[ CR = \frac{|\mathcal{C}|}{|\mathcal{C}|}; \]  

(4)

Where \( |\mathcal{C}| \) is the number of classes used in the base, and \( |\mathcal{C}| \) is the number of classes defined in the ontology.

Average Population (AP):

\[ AP = \frac{|\mathcal{I}|}{|\mathcal{C}|}. \]  

(5)

Where \( |\mathcal{I}| \) is the number of instances in the knowledgebase, and \( |\mathcal{C}| \) is the number of classes in the ontology.

From Figure 6, it is evident there are currently a total of 451 classes in the ontology, 304 relationships and 618 instances.

**Figure 6**

*EMRONT Quality Evaluation using OntoQA*

RR gives information on the diversity of the relations defined in the ontology. The RR of 40.31% is an indication that there are different types of relationships defined in EMRONT ontology schema other
than the “is-a” relationship. As the RR of the ontology tends to 100%, the more information it gives as regards the multiplicity of the types of relationships in it.

An IR is a pointer to how well knowledge is distributed into different categories and subcategories in the ontology. An IR of 5.55 may be perceived as low thereby considering EMRONT as a vertical ontology. The implication of this is that the ontology reflects a detailed knowledge of what it represents. The lower the IR of an ontology, the more detailed the ontology is in describing the knowledge it represents.

An AR of 0.03 is obviously low, showing that EMRONT may need more slots to be defined in it. It is pertinent to make clear that what the ontology engineer intends to achieve with the ontology determines how elaborate the slots defined will be in relation with the classes defined.

A CR of 40.38% shows that the instances in EMRONT are fairly distributed across the classes defined in it. A way to improve this is by populating the classes used in the base more with instances.

An AP of 1.37 is obviously not high enough. Defining more instances in the ontology for the classes, would improve the AP.

Overall, EMRONT has shown to be a sound EMR ontology enough to be refined for interoperability. However, areas of quality improvements and how to go about them have been exposed as discussed.

**MAPPING ONTOLOGY FOR INTEROPERABILITY**

Ontology mapping can simply be defined as an operation that associates the entities of one ontology to entities of another ontology or standard (Abbas & Berio, 2013). Mapping ontology to known standards to determine precision or approximation, similarities, equality, and subsumption (Harrow et al., 2019), guarantees interoperability to the degree of alignment with the standard. Ontology mapping can be formally captured as a set of common relation $c_1 R c_2|\{c_1 \in C_1 \land \{c_2 \subseteq C_2\}\}$ that can map concepts $C_1=\{c_{11}, c_{12}, c_{13}, \ldots, c_{1m}\}$ and $C_2=\{c_{21}, c_{22}, c_{23}, \ldots, c_{2n}\}$; where $C_1$ and $C_2$ are the concepts in two separate ontologies $O_1, O_2$ respectively. Mapping can be done manually, or automatically using matching tools.

After EMRONT was developed using the Noy and McGuinness’ methodology, it was mapped to SNOMED-CT in addition to aligning it with HL7 standard inline with our goal of EMRONT supporting EMR interoperability. The description of how these were achieved and the resultant mapping outcomes are exposed in the following subsections.

**Mapping EMRONT to HL7**

In aligning EMRONT with HL7, EMRONT top concepts: patient, doctor, recordstaff, hospital, record, treats, creates, etc. were manually mapped (or linked) to the core HL7 components as shown in Figure 7.

The components of HL7 in Figure 7 are in red colour while the top level concepts of EMRONT are in black. In Figure 7, for example, EMRONT has concepts as hospital and record which are entities; doctor, patient and recordStaff which are roles; while treats, creates and receivestreatment are acts. From Figure 7, it is obvious that the top concepts of EMRONT agrees with the HL7 standard. EMRONT therefore, has been shown to be consistent with the HL7 standard.
Figure 7

*Instance of Mapping of EMRONT Ontology to HL7 Messaging Standard*

Manually Mapping EMRONT to SNOMED-CT

To ensure an effective map of the EMRONT ontology to the SNOMED-CT vocabulary set, the steps elicited in Algorithm 1 were taken.

**Algorithm 1: Steps to Manually Map EMRONT to SNOMED-CT**

1. A local code system was created by extracting EMRONT concepts and attaching factored code to each of the concepts in an excel sheet.
2. The local code was then imported into the Snow Owl application – a standalone platform consisting of the SNOMED-CT vocabulary as well as other vocabularies like ICD-9, ICD-10, and LOINC.
3. Next, a complex auto-map was performed to ensure uniform synchronization of the EMRONT ontology to a standard vocabulary. Although some concept mapped partially incorrect, the snow owl reverse capability was used to align the EMRONT ontology to corresponding SNOMED-CT concept.
4. Next, a complex map reference set was produced.

The resultant map reference produced is depicted in Figure 8.
To complete the manual mapping, SNOMED-CT was converted to OWL ontology and loaded into Protégé where EMRONT was mapped to SNOMED-CT.

Semi-Automatic Mapping of EMRONT to SNOMED-CT

To reaffirm the correctness of the mapping of EMRONT to SNOMED-CT, a semi-automatic mapping and visualization tool—Snoggle—was used to align the critical top-level concepts of EMRONT to SNOMED-CT. To do this, the steps elicited in Algorithm 2 were followed.

Algorithm 2: Steps to Semi-Automatic Mapping of EMRONT to SNOMED-CT

1. Load EMRONT and SNOMED-CT files in OWL/XML format onto Snoggle.
   1.1. Load EMRONT on the “From” panel and SNOMED-CT on the “To” panel.
2. Drag EMRONT and SNOMED-CT to the left and right canvas in Snoggle respectively.
3. Click and drag EMRONT from the middle of the left canvas to the right.
4. Save the resultant map.
5. Manually inspect map.
6. If EMRONT maps correctly to SNOMED-CT exit else continue.
7. Modify EMRONT appropriately and resave.
8. Go to step 1.
To arrive at the final map, three stages were involved but this could be more, or less. At the first stage, it was observed that five out of the eight critical concepts of EMRONT mapped to seven out of the nine in SNOMED-CT. Concepts such as drug, record, medical test specimen, disease, and hospital entity mapped to substance, clinical finding, record artifact, observation, specimen, pharmaceutical product and environment as shown in Figure 9a.

**Figure 9a**

*EMRONT to SNOMED-CT Stage 1*

![EMRONT to SNOMED-CT Stage 1](image)

At the second stage, some of the concepts of EMRONT were renamed and the mapping process repeated. The result from this is depicted in Figure 9b.

**Figure 9b**

*EMRONT to SNOMED-CT Stage 2*

![EMRONT to SNOMED-CT Stage 2](image)
From Figure 9b, it is obvious that all the top-level concepts of EMRONT except Lab-experiment and Person were mapped correctly to SNOMED-CT. It was observed that SNOMED-CT does not have Person as a top concept. Again, EMRONT has Lab-test-specimen as a sub-concept of Lab-experiment, exposing this concept and repeating the mapping process ensured the top concepts of EMRONT mapped correctly to SNOMED-CT as shown in Figure 9c.

The semi-automatic mapping of EMRONT to SNOMED-CT as discussed has exposed how semi-automatic ontology mapping is done in practice and reaffirmed that semi-automatic mapping of ontology to known standards or ontology in addition to manual mapping realizes a more interoperable ontology than the use of only manual mapping.

CONCLUSION

EMR is a critical component of CIS for efficient health care delivery across the globe. This EMR potential is however threatened by interoperability problem. Although building CISs on interoperable EMR ontology is a known panacea to this problem, crafting interoperable EMR ontology has remained hitherto esoteric. This craft of building interoperable EMR ontology has been demystified by building and refining EMRONT for interoperability from scratch. The quality evaluation of EMRONT and its stepwise refinement for consistency with standard health ontology has been exposed. Competency questions and OntoQA has been used for quality evaluation while mapping EMRONT to HL7 and SNOMED-CT has been used to refine EMRONT to guarantee its interoperability. Also exposed is how semi-automatic mapping of EMRs ontology to SNOMED-CT is possible. Ontology engineers and Nursing informatics experts are encouraged to ensure EMR ontologies for building CISs are interoperable for enhanced global health care delivery and synergy among health personnel.
ACKNOWLEDGEMENT

The authors wish to acknowledge the Head of the Medical Records Unit of the University of Benin Teaching Hospital, Benin City for providing the required medical information and records used in this research.

REFERENCES

Abbas, M. A., & Berio, G. (2013). Creating ontologies using ontology mappings: Compatible and incompatible ontology mappings. IEEE/WIC/ACM International Conferences on Web Intelligence (WI) and Intelligent Agent Technology (IAT) (pp. 143–46). The Institute of Electrical and Electronics Engineers. https://doi.org/10.1109/WI-IAT.2013.169


