# Achieving Interoperability among Healthcare Standards: Building Semantic Mappings at Models Level


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## ABSTRACT

Resolving heterogeneities between data and processes paves the way for interoperability between different heterogeneous systems. Healthcare standards provide the base for interoperability between different Electronic Health Record (EHR) system. The problems related to data interoperability arise when two EHR system's are complaint to heterogeneous healthcare standards and want to communicate with each other. To achieve semantic data interoperability, there is need to resolve data level heterogeneity. In this paper, we propose system that enable high level of accuracy of mapping between heterogeneous healthcare standards model. The broader goal of data interoperability is achieved when these heterogeneities are resolved through ontology matching and generation of accurate mapping file, that helps in clinical message conversion from one standard to another. To justify claim we investigate HL7 and openEHR standards ontological mappings. We will discuss transformation of HL7 and openEHR models at high level and instance transformation at the realization level. The proposed approach provides accurate mappings that enables timely health information sharing among different healthcare systems to provide better healthcare to patients.




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## Categories and Subject Descriptors

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## Keywords

Ontology Mapping, Semantic Interoperability, Healthcare Standard, openEHR, HL7


## 1. INTRODUCTION

Information on the web and contained in knowledge bases of autonomous organizations is present in organizations required formats i.e., heterogeneous representations. The heterogeneity at conceptual level in data of two organizations is a complex problem and needs to be resolved for the purpose to share information. The heterogeneity resolution becomes critically important when the information sharing organizations are from the healthcare domain because healthcare is a complex domain in terms of complex concepts. The heterogeneity in healthcare domain is at two levels: data and process. Healthcare standards play an important role in achieving interoperability between EHR systems [14]. Each healthcare standard is based on its own objectives and goals. These include standards related to messaging (HL7)[1], terminologies (SNOMED CT), clinical information and patient records (openEHR and HL7 CDA), and imaging (Digital Imaging and Communications in Medicine (DICOM)).

[1] http://www.hl7.org/

Moreover, some initiative like Integrating the Healthcare Enterprise (IHE)[2] provide process level interoperability using existing standards. The main purpose of these standards is to provide interoperability between different healthcare systems.

Two organizations are interoperable if they are compliant with the same standard. The problem occurs when communicating parties are compliant to different healthcare standards and want to communicate with each other. An openEHR[3] compliant system cannot directly communicate with an HL7 compliant system. These standards have information overlap and at the same time differences. The information overlap is good enough to bring the standards close to each other and make them interoperable. Ontology matching is one of the methods which can effectively utilize the data overlap for achieving semantic data interoperability among different healthcare standards.

This paper focus on existing standard ontologies i.e, HL7 RIM V3 ontology[4] and openEHR ontologies[5] for ontology matching functions. The main concerning factor in resolving the heterogeneities among healthcare standards is accuracy of the mappings. The proposed system handles accuracy of healthcare standards mappings. It uses mappings based on ontology matching tools with the support of manual mappings. Ontology Matching is the process of eliminating the terminological and conceptual incompatibilities and discovering similarities between two ontologies [20]. It provides the methodology as interoperability enabler for data exchange, merging, and integration techniques. Ontology matching tools have some deficiencies that requires manual efforts in mappings generation. The proposed system uses these techniques to achieve semantic data interoperability among different EHR systems compliant to heterogeneous standards.

Semantic mappings between HL7 V3 and openEHR standards are generated using Falcon [16] and Agreement Maker [10] ontology matching tools, for matching purpose. Detailed discussion on their results and shortcomings is provided in later part of this paper. The mappings generated are used for instance conversion between HL7 and openEHR standards compliant EHR systems.

The rest of the paper is organized as follows. Section 2, explains the about HL7 and openEHR standards models and their relationship. Section 3 talks about the related work in the healthcare standards domain based on semantic mappings. Section 4, explains the proposed architecture and its components. Section 5 discusses the system working model, showing the proposed algorithms and its usage. Section 6 discusses about the bottlenecks for achieving semantic data interoperability between different standards. Section 7 is the conclusion and our future directions.

## 2. HL7 AND OPENEHR STANDARDS

HL7 V3 is a messaging standard used for communicating medical information between health information systems. On the other hand openEHR is patient records related content modeling standard related to management and storage, retrieval and exchange of health data in the form of electronic health records (EHR's). Both of these standards are based on a reference model and also follow layer of constrained models. As openEHR is based on EHR generation and manipulation, one of HL7 standard also fulfills the criteria called HL7 Clinical Document Architecture (CDA). HL7 CDA is based on Reference Information Model (RIM) for the generation of EHR document. In this paper our focus is mainly based on mappings generation between HL7 and openEHR models and also instance of HL7 CDA comparison for transformation based on mappings with instance of openEHR.

### 2.1 HL7 Models

HL7 V3 Model hierarchy can be divided into four categories: Reference Information Model (RIM), Domain Message Information Model (DMIM), Refined Message Information Model (RMIM), and Hierarchical Message Description (HMD) [9]. RIM is the root of all the information models and a critical component of V3 development process. RIM consists of backbone classes, their specialization and structural attributes for further defining the roles of the classes. The core classes are Act, Entity, Role, Act Relationship and Participation. These backbone classes are then further specialized in to sub classes which are used in DMIM and RMIM. DMIM specializes the RIM core classes and uses its sub classes based on a particular domain. An example is Laboratory DMIM that captures the information needed to support messaging related to laboratory observations, including specimen information where appropriate [21]. On the other hand RMIM's are derived from DMIM that form base for different messages in the domain, and it will be applicable to one or more Hierarchical Message Definitions (HMD) [9].

### 2.2 openEHR Models

openEHR is based on two level modeling approach, a stable reference information model constitutes the first level of modeling, while formal definitions of clinical content in the form of archetypes and templates constitute the second [12]. openEHR follows layers of constrained model and consists of EHR Information Model, Demographic Information Model, Data Structure Information Model, Common Information Model, Data types Information Model, and Integration Information Model. On the other hand the clinical content related information are handled by Template Object Model (TOM) and Archetype Object Model (AOM). Archetypes and templates are the formal models of domain concepts controlling data structure and content of data [2]. Archetypes are the constraints based models of domain content expressed in a formal language called Archetype Definition Language (ADL) [1].

### 2.3 Relationship of HL7 and openEHR

More specifically, one of HL7 standard HL7 CDA which is also based on RIM is closely aligned with openEHR. Four different types of mappings conversions are of consideration between HL7 and openEHR communities [15]; 1) HL7 Model to an openEHR archetype, 2) openEHR Archetype to HL7 Model, 3) instance of HL7 Model to instance of an

[2]http://www.ihe.net/

[3]http://www.openehr.org/

[4]Based on HL7 RIM Ballot May 2006, also partly based on Bhavna Orgun's RIM ontology http://www.ics.mq.edu.au/˜borgun/Software.html, Developed by Helen Chen and Anju Sharma, Agfa Healthcare

[5]Based on the openEHR EHR Reference Model, Developed in owl by Isabel Roman

openEHR Archetype, 4) instance of openEHR Archetype to an instance of HL7 Model.

Ontologies of both the standards are available openly covering the information related to their reference models. The different level models of HL7 and openEHR can be compared according to their scope as shown in Figure 1. RIM of HL7 V3 can be mapped with the information models of openEHR (EHR IM, Demographic IM, Data Structure IM, EHR Extract IM, Integration IM, Common IM and Support IM). The TOM and AOM openEHR models resembles with HL7's DMIM and RMIM models respectively. In similar way, HMD represents the contents of the RMIM which resembles with ADL of openEHR that represents Archetypes and Templates.

### 2.4 HL7 RIM Ontology and openEHR Ontology Mappings

The electronic Medical Agent System (eMAGS) is based on HL7 RIM based ontology proposed by Bhanva Orgun. HL7 RIM Ontology is based on RIM concepts, related HL7 data types and vocabulary [19]. HL7 RIM concept consists of subconcepts that are the backbone classes of RIM. The subconcepts are Act, Role, Entity, and Participation. HL7 Any concept in HL7 RIM Ontology represents the datatypes that includes subconcepts as datatypes such as BAG, BIN, BL, CD and others. HL7VOC concepts handles the vocabulary including subconcepts such as VocActMood, VocActState, VocAdministrativeGender, VocEntityState and VocRoleState. Figure 2 shows the structure of HL7 RIM Ontology. openEHR provides different ontologies based on their information models and the top hierarchy of the ontologies is shown in Figure 3. These ontologies are interrelated with each other and includes ontologies such as EHR_RM, Demographic_RM, Data_Structures_RM, Common_RM, Data_Types_RM, and Support_RM. These ontologies represent the information of the reference models of openEHR and their relationships with each other. EHR_RM ontology

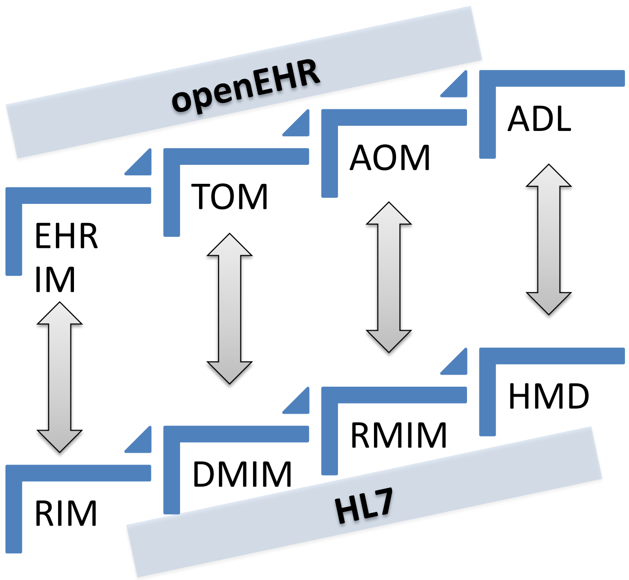


**Figure 1: Relationship of HL7 and openEHR Models**

is based on EHR Information Model (IM)that is a model of an interoperable EHR defining logical EHR information architecture [7]. This ontology imports Demographic_RM ontology . Demographic_RM ontology is based on Demographic IM representing the specification of the demographic service, containing information such as Party, Contact and Address [4]. It imports Data_Structures_RM ontology. Data_Structures_RM ontology is based on Demographic IM which describes the logical data structure including lists, tables, trees and history [3]. It imports Common_RM ontology. Common_RM ontology is based on Common IM that comprises of packages and design patterns for higher level models. The common packages include archetype, generic, directory, change control, and resource [5]. Common_RM ontology imports Data_Types_RM ontology. Data_Types_RM ontology is based on Data types IM that defines the clinical/ scientific data types including quantities, date/times, plain and coded text, time specification, multimedia, and URIs [6]. It imports Support_RM ontology. Support_RM ontology is based on Support IM that specifies semantics to be used by other reference models. The semantics are provided in the form of support packages for constants, terminology access, external resource handling and conversion information [8].

## 3. RELATED WORK

For achieving interoperability in healthcare domain, some systems have used ontology matching, SOA architecture, and also semantic web services framework. Some of these systems, closely align with the proposed system are discussed below;

Jini Health Interoperability Framework (HIF-J) [13] uses Jini technology which is based on SOA. The main purpose of HIF-J is to exchange semantically interoperable messages. It provides translation services, that behaves as a mediator between standards. These translation services convert message instances HL7 V2 and V3 and also HL7 and openEHR message instances. It is based on XSLT transformations between message instances of different standards. Since standards are growing with new domains, so managing XSLT becomes very difficult. Moreover, XSLT is just transforming syntactic structure and semantic transformation is not achieved.

Artemis [11] project is based on achieving semantic interoperability between healthcare systems by using semantic web services. It also uses the concept of semantic mediation which focuses on resolving the heterogeneities between different standards. It mainly focuses on resolving the heterogeneities between HL7 V2 and V3 standards. Artemis uses OWLmt tool which is an ontology mapping providing a graphical user interface to define the mappings between two ontology schemas. It is limited only to conversion between HL7 V2 and V3 standards.

PPEPR [23] project is an integration platform that focuses on resolving the heterogeneity problem between two version of the same standard HL7 (V2 and V3). It is based on semantic SOA concepts and solves the problem of interoperability at the semantic level. It used Web Service Modeling Ontology (WSMO) approach unlike Artemis which uses OWL-S. It mainly focuses on integration of Electronic Patient Records and conversion between HL7 V2 and V3 is specified. The scope is only limited to transformations between standards thats comes under the umbrella of HL7.

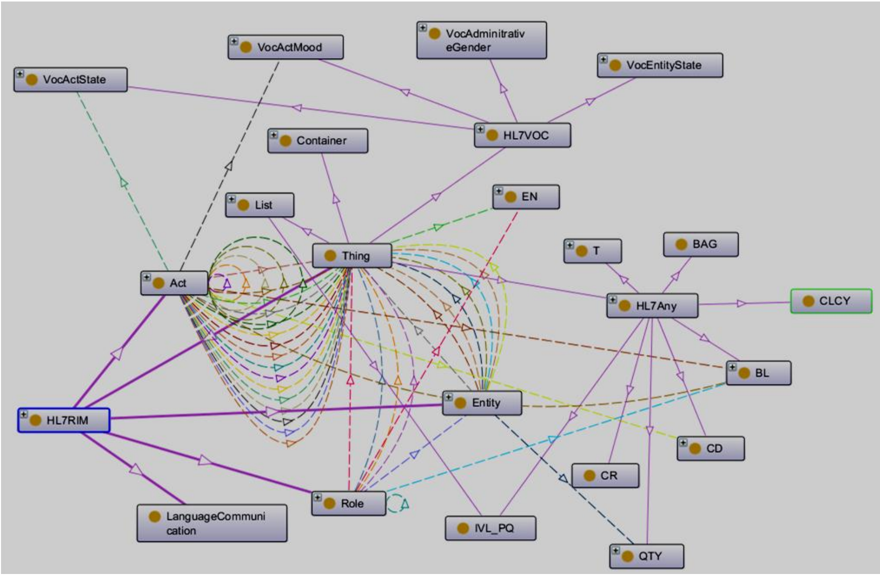


**Figure 2: HL7 RIM Ontology**

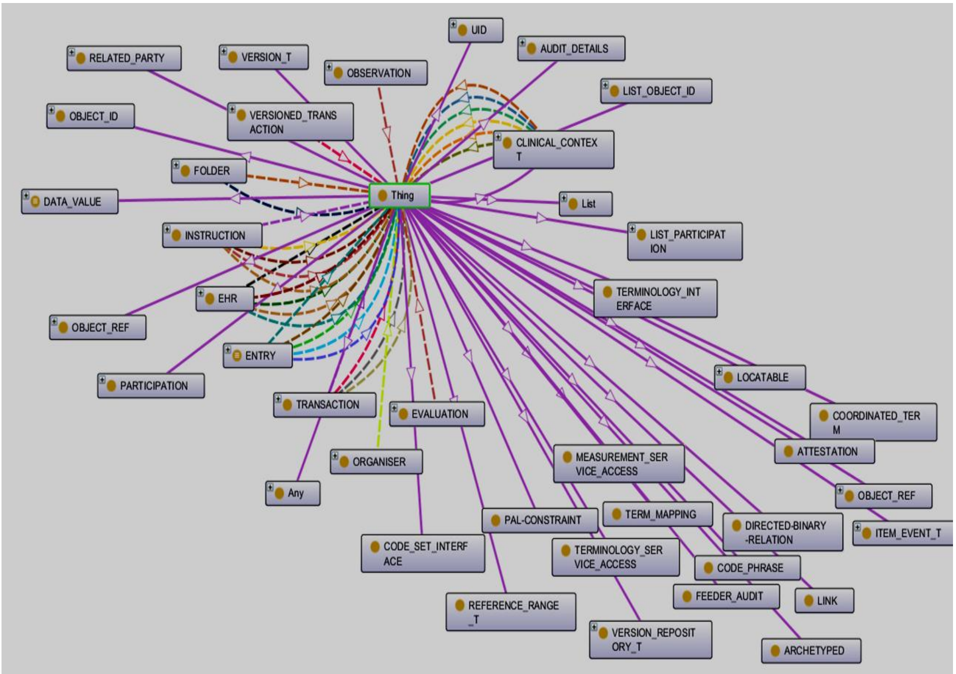


**Figure 3: openEHR Ontology**

Ortho-EPR [18] standard is a proposed standard that is based on the integration of HL7 and DICOM standards for electronic orthodontic patient records. The main purpose of this standard is storage and communication of orthodontic patient records. The message part is handled by HL7 while imaging is handled by DICOM and there integration results in Ortho-EPR standard. Its main purpose is the integration of two standards and not interoperability between standards.

In [17], the authors focus on semantic process interoperability with the help of interaction ontology in HL7 V3. Interaction ontology is responsible for handling the heterogeneities between processes of different healthcare organizations compliant to HL7 V3 standard. This work is only related to semantic process interoperability using standard HL7 V3 and semantic data interoperability is not discussed.

Existing systems mainly focuses on the conversion of instances between different standards while our focus is on the accuracy of mappings in addition to conversion of instances.

Table 1: HL7 RIM and openEHR Ontologies Mappings using Falcon and Agreement Maker

| HL7 RIM Ontology (Terms) | openEHR Ontology (Terms) | Relation | Similarity (Falcon) | Similarity (Agreement Maker) | Expert Validations |
|---|---|---|---|---|---|
| SET | SET_T | = | 0.78 | 0.78 | Correct |
| UID | UID | = | 0.76 | 1.00 | Correct |
| UUID | UUID | = | 0.73 | 1.00 | Correct |
| LIST | LIST_T | = | 0.89 | 0.78 | Correct |
| ActCluster | CLUSTER | = | 0.88 | 0.78 | Act Context = Cluster |
| Event | EVENT_T | = | 0.79 | 0.78 | History Item = EVENT_T |
| Role | ROLE | = | 0.81 | 1.00 | Correct |
| RoleAgent | AGENT | = | 0.76 | 0.78 | Device = AGENT |
| BAG | BAG_T | = | 0.91 | 0.78 | Correct |
| REAL | REAL | = | 0.88 | 1.00 | Correct |

# 4. PROPOSED ARCHITECTURE

The proposed architecture shows the use of ontology mappings for achieving interoperability among HIS's compliant to heterogeneous healthcare standards(see Figure 4). Detail description of the components are given below.

## 4.1 Communication Content Handler

This component is responsible for handling the message generation and parsing at the sender and the receiving sides of the communicating parties. It consists of sub components; HL7 Manager and openEHR Manager. Both the components are responsible for document generation and parsing. HL7 Manager generates CDA document and parses it for its validity. openEHR Manager generates and parses archetypes for enabling transfer of information.

## 4.2 Accuracy Mapping Engine

Accuracy Mapping Engine is responsible for resolving heterogeneities among healthcare standards. This engine helps in generating the mapping files that contains mappings in the form of bridge rules, responsible for conversion from one standard document format to another standard document format. It consists of the following sub components:

### *4.2.1 Ontology Matching*

The mappings are the result of ontology matching using different open source ontology matching tools available. We used Falcon and Agreement Maker for matching ontologies of these standards. The ontology mappings generated by ontology matching tools are verified by human experts for their validity. Figure 5 shows one of the bridge rule in the mapping file by comparing EntityOrganization concept of HL7 RIM V3 ontology and Organization concept of openEHR's Demographic RM ontology. The relation of both the entities is shown equal with 0.63 measuring value.

The mappings of the two specified ontologies with Falcon and Agreement Maker ontology matching tools are shown in Table 1. The table shows sample of HL7 RIM V3 Ontology concepts and openEHR ontology concepts, with relations and similarities of both the tools. The last column shows the expert validation column that is discussed in the expert verification module.

### *4.2.2 Manual Mapping Process*

It is important to eliminate discrepancies from the mappings generated by ontology matching tools. For this reason human experts performs the mapping refinement process. It assures the end to end accuracy in the whole process. Manual Mappings or human involvement is preferred as compared to Ontology Mapping component due to its precision level. The unmapped concepts would be mapped manually

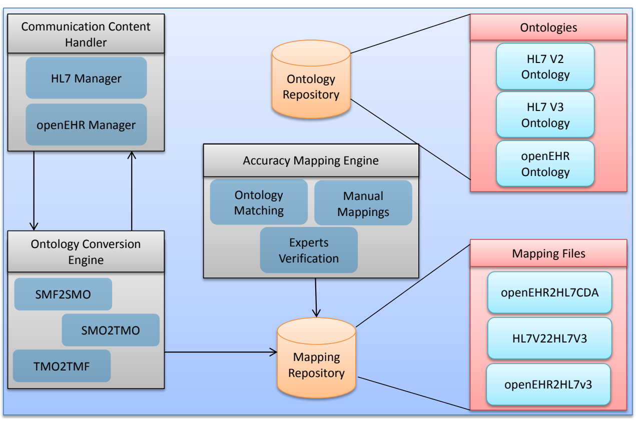


Figure 4: Proposed Architecture

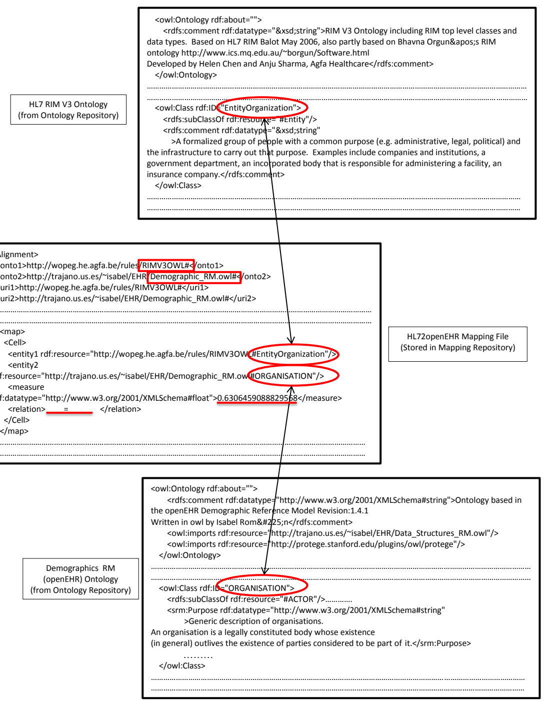


Figure 5: Mapping File Generated by Ontology Mapping Engine

based on the organizational workflow and business logic. Table 2 shows the manual mappings embedded in the mapping file that were not identified by ontology matching. The mappings are based on HL7 V3 and openEHR standards ontologies.

**Table 2: Manual Mappings between HL7 V3 and openEHR Ontologies**

| HL7 RIM Ontology (Concepts) | openEHR Ontology Concepts | Relation |
|---|---|---|
| Entity | Party | = |
| Entity | Actor | = |
| Act | Entry | = |
| Act Observation | Evaluation | = |
| Act Substance Administrator | Instruction | = |
| Act CDA Clinical Document | Transaction | = |
| HXIT | Item Event | = |

#### 4.2.3 *Expert Verification*

The criticality of healthcare domain requires verification of mapping file generated. Therefore expert verification is required for further accuracy of mappings. The experts can modify, delete or insert mappings to add to the degree of accuracy of the mapping file. Table 1 consists of column Expert Validation, finding out the inaccurate mappings.

### 4.3 Ontology Conversion Engine

This component is used for transformation of the message into formal representation for the semantics to take effect. The two sub components of this component are SMF2SMO (Source Message Format to Source Message Ontology) and TMO2TMF (Target Message Ontology to Target Message Format). SMF2SMO component performs operation by taking source message as input and converting into source message ontology. SMO2TMO component performs mappings based on the mapping file and converts SMO to TMO. TMO2TMF component takes output of SMO2TMO component and converts it to the required message format.

### 4.4 Ontology Repository

This component stores ontologies that are relevant to achieve the purpose of semantic interoperability. The Ontology Repository consists of healthcare standard ontologies such as: HL7, SNOMED CT, openEHR, and Mesh. HL7 RIM V3 Ontology and openEHR ontologies are shown in Figure 2 and Figure 3.

### 4.5 Mapping Repository

The mappings of different healthcare standard ontologies are stored in the mapping repository. The mapping ontology is in Resource Description Framework (RDF) format and is stored in Notation 3 (N3) syntax. The example shows N3 syntax of the instance REAL in HL7 RIM V3 ontology based on HL7 concepts and Support RM ontology based on openEHR concepts. The mapping instance shows the relationship of both the instances in the form of similarity which is equal is this example. In Example 4.1, (1) and (2) shows the N3 syntax of entity Real in Support RM ontology of openEHR and HL7 RIM V3 ontology. Both have properties hasOntology and hasEntityName having values of ontology URI's and entity name in URI form. In the same way, (3) shows the N3 syntax after the mapping takes place, showing similarities in type and value form.

**Example 4.1**

```
map:Entity_Instance_267
a              map:Entity ;
map:hasOntology     map:http://trajano.us.es/~isabel
                          /EHR/Support_RM.owl;
map:hasEntityName       map:http://trajano.us.es/~isabel
                    /EHR/Support_RM.owl\#REAL;
                                                  ...(1)


map:Entity_Instance_289
a                   map:Entity ;
map:hasOntology     map:http://wopeg.he.agfa.be/rules
                    /RIMV3OWL ;
map:hasEntityName   map:http://wopeg.he.agfa.be/rules
                    /RIMV3OWL#REAL;
                                                  ...(2)


map:Mapping_Instance_122470
a                   map:Mapping ;
map:hasSourceEntity map:Entity_Instance_267;
map:hasTargetEntity map:Entity_Instance_289;
map:hasSimilarityType   "=";
map:hasSimilarityValue  1.0;
                                                  ...(3)
```

The generic query for accessing mappings from the mapping file is shown in (4). The query is based on finding the mapping instance for the source and target entities of the source and target ontology.

```
SELECT ?mappingInstance ?sourceEntity ?targetEntity
?hasSimilarityType ?hasSimilarityValue ?hasSourceOntoEntity
?hasTargetOntoEntity WHERE { ?mappingInstance    a
mapping:Mapping. ?mappingInstance mapping:hasSourceEntity
?sourceEntity. ?mappingInstance mapping:hasTargetEntity
?targetEntity. ?mappingInstance mapping:hasSimilarityType
?hasSimilarityType. ?mappingInstance mapping:hasSimilarityValue
?hasSimilarityValue. ?sourceEntity    mapping:hasEntityName
?hasSourceOntoEntity. ?targetEntity    mapping:hasEntityName
?hasTargetOntoEntity. }  ...(4)
```

## 5. SYSTEM WORKING MODEL

We describe the system working model by proposed Algorithms for accuracy and message instance conversion of mappings.

### 5.1 Accuracy of Mappings Algorithms

Accurate mapping file requires three steps to be followed. Initially ontology mappings between heterogeneous standards are created and a mapping file is generated. Ontology mappings are performed using ontology matching tools e.g. Falcon and Agreement Maker. The mechanism of generation of a mapping file $Mapping_{S(i\leftrightarrow j)}$ between two different healthcare standards is described in Algorithm 1. Each entity $E_{i^o}$ in source standard ontology $SO_i$ is compared to every entity $E_{j^o}$ of target ontology $SO_j$. If the entities match then mapping file $MF$ is created.

There are some limitations of each ontology matching technique therefore not all the mappings would have been catered in this step. Therefore manual mappings are required to be performed. Manual mappings step deals with the mappings not handled through ontology matching. This step is used when manual mapping is enabled as described in Algorithm 2. FindAlignment($E_i$, $E_j$) method is used to find the mappings that were not identified through ontology matching algorithm. UpdateAlignment($E_i$, $E_j$) method

**Algorithm 1:** Ontology Mapping File Generation Algorithm

**Input**: $SO_i$, $SO_j$ /*SO is healthcare standard ontology*/
**Output**: $Mapping_{S(i \leftrightarrow j)}$

**begin**
  Ontologies: $SO_n$ /*where SO is the healthcare standard ontology, n=1,2,3...n */
  $Mapping_{S(i \leftrightarrow j)}$ MappingFileGeneration($SO_i$,$SO_j$) /*Ontology Mapping File Generation using healthcare standards ontology*/
  $ManualMapping$ = Disabled
  Create Mapping File $MF$
  **for** $E_{i^o}$ *in* $SO_i$ */* $E_{i^o}$ is element of ontology*/* **do**
    **for** $E_{j^o}$ *in* $SO_j$ **do**
      **if** *(FileAlignment($E_i$ & $E_j$))* **then**
        Store in Mapping File $MF$
      **end**
      **else**
        $ManualMapping$ = Enabled
      **end**
    **end**
  **end**
  **return** $Mapping_{S(i \leftrightarrow j)}$
**end**

is used for updating and appending the newly found mappings between source and target ontologies in the mapping file $MF$.

**Algorithm 2:** Manual Mappings additions to Mapping File Algorithm

**Input**: $MF$
**Output**: $Mapping_{S(i \leftrightarrow j)}$

**begin**
  /*Manual Mappings in the Mapping File */
  **if** $ManualMappings$ = *Enabled* **then**
    **for** *Element E in* $MF$ **do**
      FindAlignment($E_i$, $E_j$) = False
      UpdateAlignment($E_i$, $E_j$)
      Append in $MF$
    **end**
  **end**
  **return** $Mapping_{S(i \leftrightarrow j)}$
**end**

In the end when the mapping file is generated through ontology matching techniques and manual mappings, verifications of all the mappings are carried out by the domain expert. The domain expert verifies the mappings by deleting, inserting or modifying the mappings generated in the mapping file. The accuracy level of the mapping file is increased now due to the steps performed in the Algorithm 3. OperationExp($M_i$, Modify |Insert |Delete) method is used for modifying the mapping file $MF$.

## 5.2 Healthcare Standards Ontology Mapping Algorithm

The proposed algorithm is based on conversion of message instance of one standard to the required format of the message instance of another standard. Algorithm 4 takes as input $SourceMsg_{SA}$ and converts it into $TargetMsg_{SB}$ using standard mapping function.

Message Generator component is responsible for generating message as source message format $Msg_m$ that is based on a particular standard $S_n$. The message is converted from source message format to target message format by function $TargetMsg_{SB}$ StandardsMapping ($SourceMsg_{SA}$). The steps between the transformations are depicted in Figure 6. The source message format is initially converted to source message ontology. The SMO2TMO component then queries the mappings from mapping repository $Mapping^i_{S(A \leftrightarrow B)} \leftarrow$ Find_Mapping($MsgO_{SA}$), using SPARQL queries. The message is then transformed to target message format $TargetMsg_{SB}$.

**Algorithm 3:** Expert Verifications of Mapping File Algorithm

**Input**: $MF$
**Output**: $Mapping_{S(i \leftrightarrow j)}$

**begin**
  /*Domain Expert Mappings Verifications */
  **for** *Mapping* $M_i$ *in ReadFile(*$MF$*)* **do**
    OperationExp($M_i$, Modify |Insert |Delete)
    /*Exp → Expert*/
  **end**
  **return** $Mapping_{S(i \leftrightarrow j)}$
**end**

**Algorithm 4:** Message Conversion between Heterogeneous Healthcare Standards

**Input**: $SourceMsg_{SA}$ /*SA→ $Standard'A'$*/
**Output**: $TargetMsg_{SB}$ /*SB→ $Standard'B'$*/

1 **begin**
2   Standards: $S_n$ /*where S= Healthcare Standards whose ontologies are available, n= 1,2,3,...n standards*/
3   Messages: $Msg_m \in S_n$ /*where m=1,2,3,... m messages*/
4   $SourceMsg_{SA} \wedge TargetMsg_{SB} \in Msg_m$
5   $TargetMsg_{SB}$ StandardsMapping ($SourceMsg_{SA}$)
6   $MsgO_{SA} \leftarrow$ Convert ($SourceMsg_{SA}$) /*where (MsgO → MessageOntology)*/
7   $Mapping^i_{S(A \leftrightarrow B)} \leftarrow$ Find_Mapping($MsgO_{SA}$)
8   **if** *(*$SO_{\Delta i}$*) /*where* $SO_{\Delta i}$ *is any change in* $SO_i$**/* **then**
9     UpdateMappings($SO_{\Delta i}$, $SO_i$)
10     Goto Step 7
11   **end**
12   **else**
13     $MsgO_{SB} \leftarrow$ Generate($Mapping^i_{S(A \leftrightarrow B)}$)
14     $TargetMsg_{SB} \leftarrow$ Convert2TargetMsgFormat($MsgO_{SB}$)
15   **end**
16   **return** $TargetMsg_{SB}$
17 **end**

# 6. DISCUSSION

Interoperability in healthcare domain is one of the prime issues to be resolved by researchers and practitioners. The main areas of concern for interoperability are data and process. Process interoperability is related to heterogeneous workflows compatibility between organizations of the same domain. However, processes are dependent on transferring data, which is not possible unless heterogeneity in data is resolved. Therefore achieving process and data interoperability results in true semantic interoperability. Different tools, techniques, and frameworks are developed and also work is in progress to achieve semantic interoperability. The focus of this paper is on data interoperability between healthcare standards, that facilitate communication between different EHR systems for better patient care. We discuss in this section the strengths and shortcomings of different methodologies that can be used for achieving semantic data interoperability keeping in mind healthcare standards. One way of resolving heterogeneity between healthcare standards is using XSLT transformations. Message from sender using one standard is converted to the receiver standard message by XSLT transformations. This approach is not appropriate because change in schema would always result in change in XSLT transformations. This bottleneck can be resolved by having a mapping file used for handling transformations. Ontology matching provides those mappings between healthcare standards ontologies by matching ontologies for heterogeneous standards for achieving data interoperability. Agreement Maker and Falcon are used in this research due to their preciseness and accuracy as compared to other tools. Although, they generate mapping file to be used for transformation, however, still these have shortcomings. These shortcomings were identified by comparing healthcare standards ontologies. These tools lack the support for distinguishing between concepts having same name but different meanings. HL7 V3 and SNOMED CT ontology mapping leads to matching Event concept, although Event concepts in both ontologies have different meaning [22]. Event in SNOMED CT means the occurrence which results in injury while in HL7; event is the act which has taken place. The same Event concept has the same meaning as that of Clinical Finding concept of SNOMED CT ontology [22] which is not identified. This is another shortcoming of ontology mapping tools that also realizes the importance of manual mappings. The above mentioned problems are shown in Figure 7.

The concepts, Event and Clinical Finding are depicted as equal although they have different names while concepts with Event name in both the ontologies are not equal due to their meanings. Therefore, manual mappings and expert verification are used to resolve such discrepancies. Although manual mappings and expert verifications would solve the problem of having accurate mapping file, but the problem of data loss still exists.In our particular scenario implementation we have come across different hurdles. One of them is the data loss based on the conversion from one standard to another. Not all the mapping are possible between two standards, so how to cater data loss in document instance conversion. Therefore strategy to deal with the data loss is necessary for semantic data interoperability among healthcare standards.

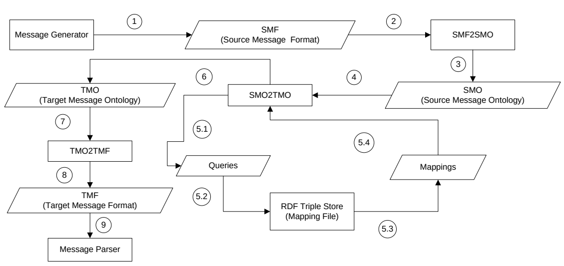


**Figure 6: Flow of Information between Components**

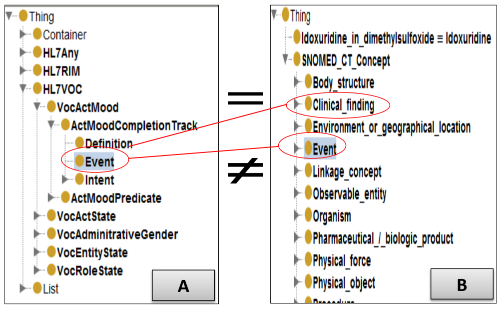


**Figure 7: (A) shows HL7 RIM Ontology; (B) represents SNOMED CT Ontology; Arrows represents HL7 and SNOMED Ontologies Conflicts**

# 7. CONCLUSION

Semantic interoperability is of prime importance for healthcare systems to communicate with each other and provide better healthcare facilities to patients. Compatibility between heterogeneous healthcare standards for message schemas conversions requires ontology matching tools. The proposed system uses ontology matching tools to resolve the data level heterogeneities between different healthcare standards and achieve message schema level conversion. Services based on ontology matching helps healthcare systems to communicate with any other system. Therefore, in future we will be working towards establishing more accurate mapping services and more detail level interaction study of existing healthcare standards mapping services based on SOA.

# 8. ACKNOWLEDGMENTS


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# 9. REFERENCES


[1] T. Beale and S. Heard. The openehr archetype model, archetype definition language, adl 2. Technical report, March 2007. (Last visited March 2011).

[2] T. Beale and S. Heard. The openehr archetype model, the template object model (tom). Technical report, March 2007. (Last visited March 2011).

[3] T. Beale, S. Heard, D. Kalra, and D. Lloyd. The openehr reference model, data structures information model. Technical report, September 2006. (Last visited March 2011).

[4] T. Beale, S. Heard, D. Kalra, and D. Lloyd. The openehr reference model, demographic information model. Technical report, Febuary 2006. (Last visited March 2011).

[5] T. Beale, S. Heard, D. Kalra, and D. Lloyd. The openehr reference model, common information model. Technical report, April 2007. (Last visited March 2011).

[6] T. Beale, S. Heard, D. Kalra, and D. Lloyd. The openehr reference model, data types information model. Technical report, April 2007. (Last visited March 2011).

[7] T. Beale, S. Heard, D. Kalra, and D. Lloyd. The openehr reference model, ehr information model.

Technical report, April 2007. (Last visited March 2011).

[8] T. Beale, S. Heard, D. Kalra, and D. Lloyd. The openehr reference model, support information model. Technical report, April 2007. (Last visited March 2011).

[9] G. W. Beeler, S. Huff, W. Rishel, A.-M. Shakir, M. Walker, C. Mead, and G. Schadow. Message development framework. Technical report, Version 3.3, Health Level Seven, Inc., December 1999.

[10] I. Cruz, W. Sunna, N. Makar, and S. Bathala. A visual tool for ontology alignment to enable geospatial interoperability. *Journal of Visual Languages & Computing*, 18(3):230–254, 2007.

[11] A. Dogac, G. Laleci, S. Kirbas, Y. Kabak, S. Sinir, A. Yildiz, and Y. Gurcan. Artemis: deploying semantically enriched web services in the healthcare domain. *Journal of Information Systems*, 31(4-5):321–339, 2006.

[12] Design principles. http://www.openehr.org/releases/1.0.1/html/architecture/overview/Output/design_principles.html. (Last visited in June 2011).

[13] A. Ducrou. Complete interoperability in healthcare: technical, semantic and process interoperability through ontology mapping and distributed enterprise integration techniques. *Doctor of Philosophy Thesis*, 2009.

[14] W. Hasselbring and S. Pedersen. Metamodelling of domain-specific standards for semantic interoperability. *Professional Knowledge Management*, pages 557–559, 2005.

[15] HL7Wiki. Openehr datatypes mapping. http://wiki.hl7.org/index.php?title=OpenEHR_datatypes_mapping. (Last visited in March 2011).

[16] W. Hu and Y. Qu. Falcon-ao: A practical ontology matching system. *Journal of Web Semantics: Science, Services and Agents on the World Wide Web*, 6(3):237–239, 2008.

[17] W. A. Khan, M. Hussain, M. Afzal, K. Latif, H. F. Ahmad, and A. Khattak. Towards semantic process interoperability. In *10th International HL7 Interoperability Conference (IHIC)*, pages 88–95, Kyoto, Japan, May 2009.

[18] A. Magni, R. de Oliveira Albuquerque, R. de Sousa Jr, M. Hans, and F. Magni. Solving incompatibilities between electronic records for orthodontic patients. *American Journal of Orthodontics and Dentofacial Orthopedics*, 132(1):116–121, 2007.

[19] B. Orgun and J. Vu. Hl7 ontology and mobile agents for interoperability in heterogeneous medical information systems. *Computers in Biology and Medicine*, 36(7-8):817–836, 2006.

[20] L. Predoiu, C. Feier, F. Scharffe, J. de Bruijn, F. Martan-Recuerda, D. Manov, and M. Ehrig. D4.2.2 stateof-the art survey on ontology merging and aligning v2. *SEKT Consortium*, 2005.

[21] Reference information model. http://www.hl7.org/v3ballot/html/welcome/environment/index. (Last visited in June 2011).

[22] A. Ryan. Towards semantic interoperability in healthcare: ontology mapping from snomed-ct to hl7 version 3. In *Proceedings of the second Australasian workshop on Advances in ontologies-Volume 72*, pages 69–74. Australian Computer Society, Inc., 2006.

[23] R. Sahay, W. Akhtar, and R. Fox. Ppepr: plug and play electronic patient records. In *Proceedings of the 2008 ACM symposium on Applied computing*, pages 2298–2304. ACM, 2008.