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Systems-Level Quality Improvement

An Adaptive Semantic based Mediation System for Data Interoperability among Health Information Systems

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Abstract Heterogeneity in the management of the complex medical data, obstructs the attainment of data level interoperability among Health Information Systems (HIS). This diversity is dependent on the compliance of HISs with different healthcare standards. Its solution demands a mediation system for the accurate interpretation of data in different heterogeneous formats for achieving data interoperability. We propose an adaptive **A**dapte**R** **I**nteroperability **EN**gine mediation system called ARIEN, that arbitrates between HISs compliant to different healthcare standards for accurate and seamless information exchange to achieve data interoperability. ARIEN stores the semantic mapping information between different standards in the *Mediation Bridge Ontology (MBO)* using ontology matching techniques. These mappings are provided by our **S**ystem for **P**arallel **He**terogeneity (SPHeRe) matching system and Personalized-Detailed Clinical Model (P-DCM) approach to guarantee accuracy of mappings. The realization of the effectiveness of the mappings stored in the *MBO* is evaluation of the accuracy in transformation process among different standard formats. We evaluated our proposed system with the transformation process of medical records between Clinical Document Architecture (CDA) and Virtual Medical Record (vMR) standards. The transformation process achieved over 90 % of accuracy level in conversion process between CDA and vMR standards using pattern oriented approach from the *MBO*. The proposed mediation system improves the overall communication process between HISs. It provides an accurate and seamless medical information exchange to ensure data interoperability and timely healthcare services to patients.

Keywords Health information system · Semantics · Standards · HL7 · Ontology · Interoperability

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Introduction

Medical data heterogeneity, complexity and its continuously increasing size has acquired the attention of many research fields. Big data involvement in the medical domain is considered a revolution for personalized healthcare [1]. The increase in heterogenous medical data sources demands mediation for exchange of information between Health Information System (HIS). These HISs are compliant to conflicting standards which result in lack of communication among them due to gaps in medical standards [2]. So the bottleneck for these HISs is their compliancy with different healthcare standards. The solution to handle complex medical data exchange is achieving interoperability. Technical and semantic interoperability can only be achieved when existing standards are harmonized and bridged [3]. Therefore, mediation systems can play critical role in interoperability among HISs compliant to heterogeneous HISs.

Mediation systems provide common platform that understands the sender and receiver's HIS compliancy with heterogeneous standards and interprets information accordingly. This can be observed from the Clinical Information Modeling Initiative (CIMI) international collaboration initiative taken by healthcare standardization bodies with the motive "dedicated to providing a common format for detailed specifications for the representation of health information content so that semantically interoperable information may be created and shared in health records, messages and documents" [4]. Mappings generation and storage provides a way for common information storage. To quantify the efficiency of a mediation system, accuracy and evolution of mappings tend to be the two substantial factors for achieving data interoperability. To measure the effectiveness of accuracy and continuity of the mappings, a mediation system must have a transformation process for conversion among different standard formats.

We propose an adaptive **A**dapte**R** **I**nteroperability **EN**gine (ARIEN) as a mediation system to resolve heterogeneity among HISs compliant to heterogeneous medical standards for achieving data interoperability. The proposed system is adaptive as it can be used for data interoperability among any medical standards. ARIEN provides data interoperability services by addressing accuracy and continuity of mapping aspects. **S**ystem for **P**arallel **He**terogeneity **Re**solution (SPHeRe)[1] [5] [6] and Personalized-Detailed Clinical Model (P-DCM) [7] approaches are used for accuracy of mappings. We developed SPHeRe as an ontology matching tool to generate mappings between medical ontologies and store them in the *Mediation Bridge Ontology (MBO)* (a mapping representation ontology). *MBO* adopts ontology alignment patterns-oriented approach for semantic mapping information storage between heterogeneous standards. P-DCM approach handles the organization conformance details and results in evolution for continuity of mappings. We have done preliminary evaluation for continuity of mappings by introducing a self evolutionary rule based scheme [8]. The main focus of this paper is to measure the effectiveness of the mappings generated and stored using the above mentioned approaches. This objective is achieved by Mapping Authoring and Mapping Execution Environment. This is performed by evaluating the transformation process of the proposed ARIEN system to measure the effectiveness of accuracy and continuity of mappings for achieving data interoperability.

The scenario for data interoperability discussed in this paper is information exchange among two HISs compliant to different medical standards. HMIS[2]/EHR/EMR systems compliant to HL7 Clinical Document Architecture (CDA) standard are the communicating HISs with Clinical Decision Support System (CDSS) compliant with HL7 Virtual Medical Record (vMR) as the other HIS. Therefore effectiveness of the mappings stored using SPHeRe and P-DCM approach is measured by the transformation process from CDA to vMR standard format and vice versa. The proposed system transformation process achieved over 90 % of accuracy level in conversion process between CDA and vMR standards. The proposed mediation system improves the overall communication process between HISs.

The rest of the paper is structured as follows: section "Background" explains an example of a CDSS that is utilizing the functionalities of the proposed system for the purpose of interoperability. section "HL7 CDA and vMR standards" introduces HL7 CDA and vMR standards, and their structures, concepts and role in HISs. Existing literature that focuses on different aspects of interoperability is highlighted in section "Related work". The internal details and workflow of the system is described in section "Proposed architecture and methodology". The system is evaluated by measuring accuracy between standards transformation in section "Evaluation". section "Discussion" explain the challenges faced while implementing the system, and section "Conclusion" concludes the paper by providing summary details of the proposed system and its future directions.

Background

This section describes the background information necessary to understand the proposed system. Currently, the proposed system works as an adapter to Smart CDSS [9], an initiative taken in our lab [3] to develop a clinical decision support system that provides recommendations and guidelines to physicians and patients. The proposed system is divided into two layers: *Mapping Authoring Environment* and *Mapping Execution Environment*. *Mapping Authoring Environment* generate and store the mappings in the *MBO*, while *Mapping Execution Environment* uses these mappings for transformation from one standard format to another. The mappings in the *MBO*, generated and stored in *Mapping*

[1] http://uclab.khu.ac.kr/sphere

[2] Heath Management Information System

[3] http://uclab.khu.ac.kr/

Authoring Environment, are categorized into generalized and customized mappings. These categories of mappings help in measuring the effectiveness of mappings. This paper focuses on how the mappings are generated and stored in the *MBO*; and then utilized by the *Mapping Execution Environment* in transformation process between CDA and vMR standards (case study for Smart CDSS). Therefore, we discuss Smart CDSS, *SPHeRe* and *P-DCM* approaches, and *MBO* as background for understanding the proposed system.

An overview of Smart CDSS

Smart CDSS is standard based clinical decision system that provides recommendations to physicians and patients based on heterogeneous data sources including clinical data, social media data, behavior modeling data, and activities and emotion recognition data [10] [11]. Among its different features, interoperability of HISs and smart homes compliant to different standards with Smart CDSS is a key challenge. This kind of interoperability is considered data level interoperability which is the ability to communicate data among systems with the original semantics of the data retained irrespective of its point of access [12]. This challenge can be resolved by resolving heterogeneity between different heterogeneous healthcare standards.

Smart CDSS consumers include systems that are compliant to different healthcare standards. Smart CDSS can only process information in vMR standard. Therefore, an adapter is required to transform HMIS compliant healthcare standard to Smart CDSS compliant healthcare standard and vice versa. The proposed ARIEN system facilitates Smart CDSS in achieving interoperability with different HISs. We are considering HL7 CDA standard for HISs and smart homes compliancy and developed HL7 CDA and vMR ontologies based on their specifications. The proposed system ARIEN is part of the Adaptability Engine as shown inFig. 1.

SPHeRe and P-DCM approach

We have designed and developed *SPHeRe* system that is an ontology matching system used in this case for matching medical standard ontologies to generate generalized mappings. It uses different bridge algorithms to generate mappings and store them in a particular format addressed by the *MBO*. For example, *Overlap Bridge* matches concepts based on class, attributes, and their value by using *Overlap Pattern Relationship Model* and stores the mapped information between ontologies in the *MBO*. The problem with generalized mappings is its inability to accommodate organizational conformance information. Organizations can conform to particular concepts, and the non-conformed concepts lead to some of stale generalized mappings. These organizational conformance based mappings are categorized as customized mappings and our approach P-DCM manages these mappings. Further detail about these approaches is provided in section "Proposed architecture and methodology".

Mediation bridge ontology (MBO)

MBO is a bridge ontology that is based on ontology design patterns and stores alignments between matching ontologies. *MBO* is categorized into two main classes *MediationBridge* and *PatternClass*. *MediationBridge* is divided into syntactic and structural bridge subclasses: *String Matching Bridge, Label Bridge, Synonym Bridge, Polysemous Bridge, Overlap Bridge, Customized Bridge, CBSB,* and *PBSB*. These bridge classes are used to represent the alignments generated from particular algorithms in their specified format. These are dependent on *PatternClass* for structuring the output of the alignment process. *PatternClass* include *MappedSequence, Standard1Class, Standard2Class, Match, MappedClass, ClassLabel, ListStandard1,* and *ListStandard2* subclasses. These are used to provide the structure for representation of the alignment in the *MBO*. The overall hierarchy of *MBO* is shown in Fig. 2.

HL7 CDA and vMR standards

Medical standards play a vital role towards interoperability among HISs. HL7 provides a family of standards for

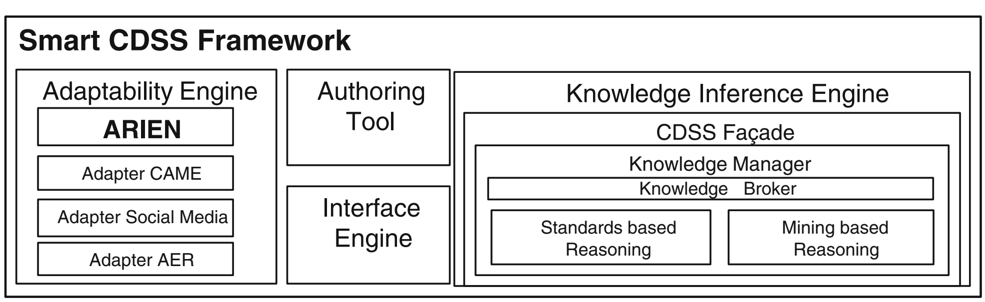

Fig. 1 Architecture of Smart CDSS [9]

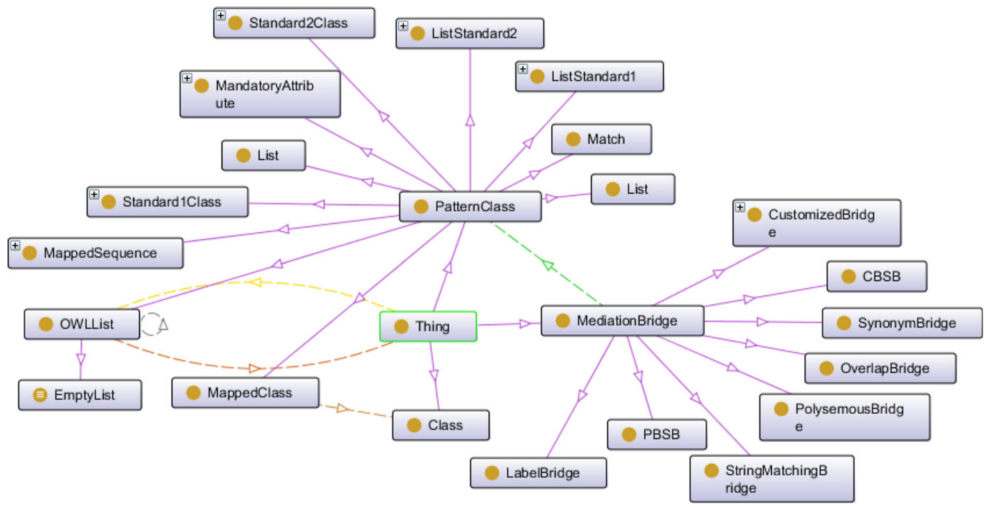

Fig. 2 Mediation Bridge Ontology

achieving this goal. Some of the HL7 standards that we are currently using in our Smart CDSS version discussed in the previous section include HL7 CDA, vMR, Medical Logic Module (MLM), and Arden Syntax. HL7 CDA is used for medical document generation and exchange by the HMIS. HL7 vMR is the medical record that is used by the Smart CDSS system for the processing of medical information. MLM is the standard used for representing the clinical guidelines that can be used in the decision making process [13]; these are examples of sharing via a common knowledge representation format [14]. MLM's are written in Arden Syntax to represent clinical and scientific knowledge in an executable format [15].

HL7 CDA and vMR are our case study standards for data interoperability between HMISs compliance with CDA and CDSSs compliance with vMR. Both of the standards are based on the HL7 Reference Information Model (RIM) [16] that is the root of all the information models and consists of backbone classes, and their specialization and structural attributes for further defining the roles of the classes. The core classes are Act, Entity, Role, Act Relationship and Participation. The RIM is specialized into Domain Message Information Model (DMIM) that specializes the RIM core classes and uses its sub classes based on a particular domain. The DMIM is specialized into Refined Message Information Model (RMIM) that forms a base for different messages in the domain, and it will be applicable to one or more Hierarchical Message Definitions (HMD) [16]. HL7 CDA follows a CDA RMIM [17] that contains information about document creation and manipulation. A CDA document can be transferred within a message or independently [18]. The skeleton structure of CDA record is shown in Table 1 (as CDA Skeleton). Likewise, a vMR is also an HL7 standard that is based on the RIM and is used in clinical decision support (CDS). VMR is a data model for representing clinical data relevant to CDS by recording patient's demographics and clinical history data [19]. It is divided into two types of structures: vMR Input and vMR Output. VMR Input models the input information of the patient and, after processing and guidelines generation, vMR Output is used to model that information. VMR Input is shown in Table 1 (vMR Skeleton). Integration of HMIS compliant to CDA and CDSS compliant to vMR requires transformation between these standards; Table 1 shows the Structural transformation pattern when conversion from CDA to vMR Input is necessary. On the other hand, vMR Output is converted to CDA when guidelines are generated and are communicated with HMIS. The details of the mapping creation process and pattern transformation are discussed in later sections.

Related work

Mediation systems mostly are dependent on common mappings that behave as a bridge between communicating systems. Many aspects are associated with such mediation systems for data management such as data capturing, data integration, data storage, data refinement, and data transfer. Jens et al. [20] proposed Central Data Management (CDM) system that focused on achieving the mentioned aspects for data management. Complexity of CDM approach arises when the amount of data and its associated resources involved in communication increases [20]. A mediation ontology can store this complex information and regulate the flow of information for data management. One such type of mediation ontology, commonly known as bridge ontology, is part of the literature, initially introduced

Table 1 Structural transformation pattern

CDA Skeleton	vMR Skeleton
<?xml version="1.0"?>	<?xml version="1.0" encoding="UTF-8"?>
<ClinicalDocument xmlns="urn:hl7-org:v3"	<cdsInput xmlns="urn:hl7-org:v3/vmr"
xmlns:voc="urn:hl7-org:v3/voc"	xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"	xmlns:dt="urn:hl7-org:v3/cdsdt"
xsi:schemaLocation="urn:hl7-org:v3 CDA.xsd">	xsi:schemaLocation=
<typeId root="" extension=""/>	"urn:hl7-org:v3/vmr ..\Schemas\cdsInput.xsd">
<templateId root=""/>	<templateId root=""/>
<id extension="" root=""/>	<cdsContext>
<code code="" codeSystem="" codeSystemName="" displayName=""/>	<cdsSystemUserPreferredLanguage code=""
<title> </title>	codeSystem="" displayName=""/>
<effectiveTime value=""/>	</cdsContext>
<confidentialityCode code="" codeSystem=""/>	<vmrInput>
<languageCode code=""/>	<templateId root=""/>
<setId extension="" root=""/>	<patient>
<recordTarget> </recordTarget>	<id root="" extension=""/>
<author> </author>	.....
<custodian> </custodian>	</patient>
<component>	</vmrInput>
<structuredBody>	</cdsInput>
....	
</structuredBody>	
</component>	
</ClinicalDocument>	

in [21, 22], to the best of our knowledge. The proposed system takes this concept as a baseline for the development of the *MBO* for data interoperability among HISs. Some of the existing systems with the objective of interoperability are discussed in this section.

Biomedical ontologies matching systems

Ontology matching systems that focus on resolving heterogeneity between biomedical ontologies assist in achieving interoperability. Two approaches based on matching biomedical ontologies are the System for Aligning and Merging Biomedical Ontologies (SAMBO) and Automated Semantic Matching of Ontologies with Verification (ASMOV). SAMBO [23] is an ontology merging system based on matching biomedical ontologies. SAMBO involves users for the creation of every alignment that becomes a hurdle in the automatic generation of new ontology. Another ontology matching approach for information integration in the field of bioinformatics is ASMOV [24]. Similarity calculation and semantic verification are the two main steps of this approach; it uses WordNet and UMLS for increasing the accuracy level in the similarity calculation. The primary focus of these two systems is on biomedical applications [25] and also lack consideration of ontology mapping representation.

CDSS projects for interoperability

The role of ontologies becomes more important in the path towards interoperable CDSSs. This is highlighted in [26], by describing the role of biomedical ontologies based on healthcare standards to manage knowledge management, data integration and interoperability aspects and their fusion for decision support systems. Another project is SAPHIRE, a multi agent system supported by an intelligent decision support system to improve patients' lifecare by monitoring their activities. It depends on semantically enriched web services for communicating information to tackle interoperability [27]. An HL7 CDA wrapper based CDSS system is proposed in [28]. This work is based on achieving semantic interoperability in rule based CDSS. The objective is achieved with standardized input and output documents conforming an HL7 CDA wrapper. The system is only dependent on HL7 CDA and lacks external mapping handling of non-HL7 CDA Health Information Systems (HIS).

Medical standards based mediation systems

Prominent work in literature with interoperability as objective among different healthcare standards include: Artemis (semantic mediation between different Health Information Systems (HIS)) [29], PPEPR (resolving heterogeneity between HL7 v2 and v3) [30], LinkEHR (tool used for transformations among standards such as HL7, openEHR and CEN 13606) [31], and Poseacle Converter (CEN 13606 and openEHR standards archetypes and extracts transformation and validation) [32]. Ozgur Kilic et al. [33] proposed mapping algorithms that resolves integration issues by handling transformation among HL7 clinical statements instances and EHRcom instances. There exists our work on process interoperability among different HISs compliant to HL7 standard having heterogeneous workflows [34]. It lacks in the data interoperability aspects which complements the process interoperability. Pieterjan et al. [35] proposed multiple healthcare providers data aggregation platform for decision support system to achieve interoperability. A proof of concept is created for the use of semantic web technologies for enabling interoperability between healthcare providers by aggregating multiple sources data for decision support service [35]. This work possess limitation of not covering the mapping generation and storage aspects from ontologies to be used in data aggregation and transformation. SAMS [36] architecture is based on use of agent technology for health information systems to store patients electronic health records, and provide assistance to physicians in decision making. Although this work provide details of the use of ontologies and rules for decision support, it lacks providing insight into interoperability for resolving heterogeneity among different HIS compliant with heterogeneous standards.

Comparison with proposed system

In summary, some factors are observed that are the building blocks for interoperability. These includes: Medical Systems, Biomedical Ontologies, Medical Standards, and Matching Systems. The above mentioned systems lacked at least one of these blocks therefore they are considered as the path towards interoperability. The proposed systems, unlike these systems, provide a complete package for mediation systems to achieve true data interoperability. Accuracy and continuity of mappings provide the umbrella for all the building blocks. This complete package, known as ARIEN, is thoroughly elaborated and investigated in the next sections.

Proposed architecture and methodology

The proposed system ARIEN's goal of achieving data interoperability is dependent on the accuracy and continuity of mappings. The system works on employing two processes for achieving the objective: *Mappings Authoring Environment* and *Mapping Execution Environment*. The mappings generation process is an offline process to generate mappings using ontology mediation techniques while standards transformation process is an online process for HIS utilizing the mapping service for conversion between standard formats for information exchange. The mappings generation process provides the base for accuracy and continuity of mappings, and standard transformation process measures the level of accuracy and continuity of mappings achieved by the mapping generation process. The proposed system is divided into three primary modules: *Accuracy Mapping Engine*, *Standard Ontology Change Management* and *Transformation Engine* as shown in Fig. 3. We categorize them based on processes and provide the details as follows:

Mapping authoring environment

This process is based on using different standards information for generating and storing mappings. The steps include the creation of ontologies from standards specification, validation of ontologies, loading of heterogeneous ontologies, matching ontologies, storing mappings, and expert verifications. Mapping generation process creates the foundation for accuracy and continuity of mappings for achieving data interoperability. The process consists of *Accuracy Mapping Engine* and *Standard Ontology Change Management* modules. *Accuracy Mapping Engine* module is responsible for accuracy of mappings by generating mappings between heterogeneous medical standards and storing them in a mapping repository using ontology matching techniques. The *Standard Ontology Change Management* module deals with the ontology change management aspect of the process for evolution in the mappings.

Accuracy mapping engine

This component deals with applying the bridge algorithms for the generation and storage of ontology mappings between two matching medical ontologies. It takes as input any two medical standards ontologies for the matching process. In our case, we are focusing on CDA and vMR standards and developed ontologies for each using their standard specifications. Mappings generation is divided into three step process: generalized mappings generation, customized mappings generation and expert verifications.

We developed an ontology matching tool called *SPHeRe* for generating generalized mappings between medical ontologies. SPHeRe is an effective ontology matching system that performs computationally intensive opera-

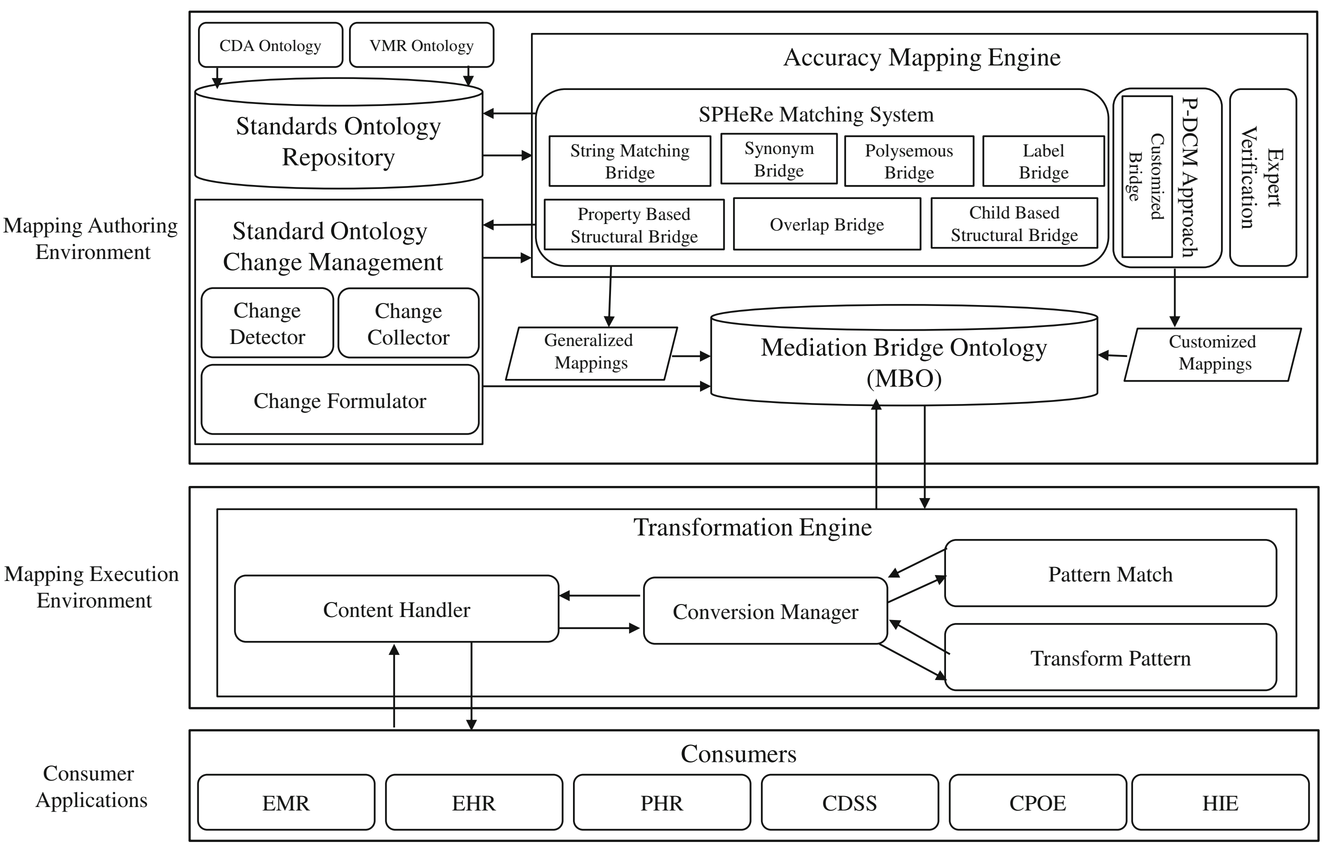

Fig. 3 ARIEN Proposed Architecture

tions using optimized matching algorithms executed over matched medical ontologies. It is a high performance-based initiative that improves ontology matching performance by exploiting parallelism over multicore commodity hardware of Cloud Platform [37]. It consists of different bridge algorithms for generalized mappings generations as shown in Fig. 3. *String Matching Bridge* is used to identify similar concepts in the matched ontologies using string matching techniques. *Synonym Bridge* identifies similar meaning concepts by utilizing information from online dictionary available, such as WordNet [38]. *Label Bridge* match labels of matching concepts stored in the ontologies to identify similar labels for concluding matched concepts as similar concepts. It also uses string matching techniques for matching labels of the concepts. *Overlap Bridge* finds concepts that contain overlapping information and are necessary for information exchange. It uses structural hierarchies' information for finding overlapping concepts. *Polysemous Bridge* validates the exact match concepts similarity by using online dictionary to compare meaning of the concepts. It identifies concepts having same name but different meanings. *Child Based Structural Bridge* and *Property Based Structural Bridge* use concepts children similarity matching and property similarity matching techniques to find similar concepts in matching ontologies. Ontology alignment patterns are also used in these bridge algorithms for alignments in ontology mediation process. Some of these patterns are discussed in section "Medical standards conversion process". The implementation details of these bridge algorithms are beyond the scope of this paper. These algorithms are used for generating *Generalized Mappings* between medical ontologies and then storing them in the *MBO*.

Organizational conformance with concepts based on their requirements effects the accuracy of mappings and is handled by *P-DCM* approach. The information of conformance with specific concepts and non-conformance with particular concepts categorizes these mappings as *Customized Mappings*. *P-DCM* approach focuses on the generation of *Customized Mappings* that creates the necessary linkage between organization's conformed medical standards concepts and clinical model concepts to ensure data interoperability among HISs [7]. *Customized Bridge* is used to represent P-DCM based mappings between medical standard ontologies and storing these in *MBO*. *P-DCM ontology* annotates the clinical model concepts with different standard concepts and also represents the non-conformed concepts. The non-conformed concepts are responsible to invalidate some of the mappings in generalized mappings. Therefore, deprecating those mappings is necessary for smooth information exchange for a particular organization's HIS communication processes with other HISs. In summary, *Customized Mappings* in addition to *Generalized Mappings* helps in improving the overall accuracy of the mappings.

The *MBO* is the mapping repository that stores the *Customized* and *Generalized* mappings generated by *SPHeRe* and *P-DCM* approach. It's called *MBO* because it is the centralized mediation point for all the other components of ARIEN system. *Accuracy Mapping Engine* stores mappings in it, *Standard Ontology Change Management* applies change management for evolving mappings, and *Transformation Engine* uses these mappings for transformation from one standard format to another. Automation of alignments generation and storage, scalability for adding more bridge algorithms and evolution to changes are the features of *MBO*. Also, it focuses on the mapping representation aspect for management and reuse of the stored alignments. Expert verification of the *MBO* mappings is required after the mapping generation process is completed for further strengthening the accuracy of mappings. Medical domain directly impacts life-care therefore importance of expert verification cannot be denied, thus it is considered part of the *Accuracy Mapping Engine*.

Standard ontology change management

Customized Mappings invalidates some of the *Generalized Mappings* in the *MBO* due to organization's conformance issues by bringing change to the existing mappings. These changes are necessary for mappings evolution to ensure continuity of mappings. *Standard Ontology Change Management* component executes change management functions to evolve the mappings for changes to take effect in the *MBO*. *P-DCM ontology* contains all the information about conformed and non-conformed concepts and relationship of clinical model concepts with different standard concepts. *Customized Mappings* can influence *MBO* by insertion, deletion, and modifications of mappings. The steps involved in this component are as follows:

- *Change Detector* listens for non-conformed concepts information from the *P-DCM ontology*.
    - Non-conformed concepts are accessed from *P-DCM ontology*.
    - Mappings based on non-conformed concepts are identified in the *MBO* and stored as stale mappings.
    - A single stale mapping is composed of a conformed concept aligned with a non-conformed concept.
- *Change Collector* accesses stale mappings from *Change Detector*.
    - Conformed concepts are collected from the stale mappings.

  - Annotated mappings based on the conformed concept are searched in the *P-DCM ontology*. A corresponding conformed concept of the target standard concept is identified from the annotated mapping information. For example, if the conformed concept *A* belongs to standard 1 and non-conformed concept *B* belongs to standard 2, then based on *A* its corresponding conformed concept *C* of standard 2 is accessed from *P-DCM ontology* and an annotated mapping is generated.
  - *P-DCM ontology* annotated information are also searched to find out some new mappings that didn't existed before for storing in the *MBO*. For example, concept *X* and *Y* of standard 1 and 2 are related with clinical model concept *Z* in *P-DCM ontology* which is the annotated information. Concept *X* and *Y* are candidate alignment in this case, therefore if this alignment is not already present in the *MBO* then it is a new candidate mapping.
- *Change Formulator* collects the modified and new mappings identified by *Change Collector* and formulates it in *MBO* compatible format for storing.

The whole change management process discussed above is intended to accomplish continuity of mappings. Continuity of mappings complements accuracy of mappings to achieve data interoperability among HISs. This paper only highlights the procedure for continuity of mapping issue for data interoperability and thoroughly describes the standard transformation process using mappings stored in the *MBO*.

Mapping execution environment

Measuring the level of effectiveness of accuracy and continuity of mappings determines the degree of data interoperability accomplished among HISs. *Mapping Execution Environment* provides realization to a certain level of effectiveness of data interoperability among HISs. This includes structural, sequential and data transformation mechanism to convert and generate valid medical standard formats. We consider mapping based transformation between HL7 CDA and vMR standards for proof of concept and evaluating the ability of the proposed system to achieve data interoperability. Legacy HISs can utilize the medical standard transformation services of this step directly and communicate with other HISs. The component of ARIEN system that is responsible for performing activities of converting from one standard format to another and vice versa is *Transformation Engine*.

Transformation engine

This component executes mediation strategy designed for enabling communication between HISs that are compliant with heterogeneous medical standards. It consists of four sub-components:

- *Content Handler* that communicates with communicating HISs in their complaint standard formats.
- *Conversion Engine* that executes the actual transformation process between different standards.
- *Pattern Match* finds the most suitable alignment from the *MBO* by matching the input pattern.
- *Transform Pattern* converts input pattern to output pattern by using the pattern match infomation obtained from the *MBO*.

We assume that HMIS compliant with CDA standard wants to take benefits from CDSS compliant with vMR standard. Therefore, HMIS communicates with *Content Handler* and provides clinical document containing patient information in CDA format. The basic purpose is to obtain recommendation from CDSS that is compliant to vMR standard. *Content Handler* forwards information to *Conversion Engine* for applying transformation process, that uses *Pattern Match* to identify the matched pattern from the *MBO* based on the input information. It then forwards the pattern match information to *Transform Pattern* that converts the input information of one standard format to output format of another standard format using pattern identified from the *MBO*. In this scenario, CDA standard format requires to be transformed to vMR format for CDSS processing. *Conversion Engine* converts CDA to vMR by applying transformation patterns modeled in *MBO*. CDSS processes information; generates recommendation in vMR output format that is converted back to CDA format by *Conversion Engine* using *Pattern Match*, and *Transform Pattern* modules. The final recommendation information is provided to HMIS via *Content Handler* and thus data interoperability is achieved. The transformation process is described in Algorithm 1&2.

MBO based transformation algorithms

The process of instance level transformation among different standards is described using algorithms in this section. Algorithm 1 explains the procedure of source standard instance SMR_SA conversion to target standard instance TMR_SB. The conversion is based on loading the patterns stored in the *MBO* using *LoadMBO()* method. Initially, the target instance is empty $TMR_{SB} = \emptyset$ and the concepts from source instance is retrieved SMR_{SA}.RetreiveConceptsList() for instance transformation. Mapping of these retrieved concepts with target standard concept is performed by

RetrieveMappings($ListConceptsSMR_{SA}$, MBO) method that is described in Algorithm 2.

Algorithm 1 Heterogeneous Medical Standards Transformation

```
Input: SMR_SA /*MR → Source Medical Record & SA→ Standard'A'*/
Output: TMR_SB /*MR → Target Medical Record & SB→ Standard'B'*/
begin
    Let MBO := LoadMBO() /* where MBO is Mediation Bridge Ontology */
    Let TMR_SB = ∅
    ListConceptsSMR_SA ← SMR_SA.RetreiveConceptsList()
    ListMappedConceptsTMR_SB ← RetrieveMappings(ListConceptsSMR_SA, MBO)
    ListConceptsTMR_SB ←
    TMR_SB.InsertConceptList(ListMappedConceptsTMR_SB)
    Let SC_t ← ListMappedConceptsTMR_SB.first()
    for SC_i ϵ ListConceptsSMR_SA do
        SC_t.Value ≡ SC_i.Value
        SC_t ← ListMappedConceptsTMR_SB.next()
    end
    return TMR_SB
end
```

Algorithm 2 executes until all the corresponding concepts and properties of the source standard are identified from the *MBO* using patterns match. The corresponding target concepts TC_j and target properties TCP_j are matched from the source corresponding concepts from the *MBO* using MBO.FindCorrespondingConcept(SC_i) and MBO.*FindCorrespondingProperty*(SCP) *methods respectively*. *FindCorrespondingConcept()* and *FindCorrespondingProperty()* methods uses the different patterns for finding the appropriate concepts and properties. These mapped concepts of target standard $ListConceptsTMR_{SB}$ are returned to the *RetrieveMappings*($ListConceptsSMR_{SA}$, MBO) of Algorithm 1.

Algorithm 2 Pattern Oriented Standard Structure Mapping

```
Input: ListConceptsSMR_SA, MBO
Output: ListConceptsTMR_SB
begin
    Let SC_i is Source Ontology Concepts
    while SC_i ← ListConceptsSMR_SA.next() do
        TC_j ← MBO.FindCorrespondingConcept(SC_i)
        SCP_i := SC_i.GetProperties()
        for SCP ϵ SCP_i do
            TCP_j ← MBO.FindCorrespondingProperty(SCP)
            TC_i.add(TCP_j)
        end
        ListConceptsTMR_SB.add(TC_i)
    end
    return ListConceptsTMR_SB
end
```

Algorithm 1 utilizes the mapped concepts $ListConceptsTMR_{SB}$ from Algorithm 2 and insert it into TMR_{SB} using TMR_{SB}. *InsertConceptList* ($ListMappedConceptsTMR_{SB}$) method. The values are finally assigned to all the matched concepts using SC_t.Value $\equiv$ SC_i.Value statement and the target standard instance TMR_{SB} is generated. The transformation patterns with the help of CDA and vMR standards case study is demonstrated in the next section.

Medical standards conversion process

Standards follow structured format based on reference model that provides clearly defined concepts for interoperable communication among HISs. Their transformation mechanism among each other using *MBO* is described in detail in this section. We take the case of CDA and vMR standards as discussed previously. The proposed system ARIEN is a data mediation system that uses transformation patterns using *MBO* for conversion between CDA and vMR standard medical records.

VMR is a medical record therefore most of the linkage of information in this format is with the structured body portion of CDA. Table 2 shows CDA and vMR snippet code based on patient's systolic and diastolic blood pressure record in standard based structured format. The proposed ARIEN system is responsible for providing gateway to HISs for exchanging meaningful information with each other by standard format transformation. It converts HMIS compatible CDA format to CDSS compatible vMR format and vice versa for processing of information.

Table 2a shows structured body portion of CDA by using **Observation** class to record patient blood pressure. The main classes used for recording this observation are **Component, Section, Entry, Observation, and Entry Relationship**. **Observation** class records systolic and diastolic blood pressure and relates with each other through **Entry Relationship** class. In the same way, to model the same information in vMR requires use of **ObservationResult** class. The main classes therefore used in vMR format are **ObservationResults, ObservationResult, and RelatedClinicalStatement** as shown in Table 2b. **ObservationResult** class maps to **Observation** class as it records systolic and diastolic blood pressure results and **RelatedClinicalStatement** class behaves as **Entry Relationship** class to relate results information. We describe the realization of alignment and transformation patterns required for conversion between these standards by carrying forward the scenario described in this section.

Ontology alignment patterns behave as reusable templates of recurring correspondences and plays vital role in achieving interoperability [39]. The patterns for conversion are divided into three main categories: Structural, Sequence and Data Transformations. Initially, output structure is defined for the conversion format based on the input format. This type of pattern is called Structural Transformation Pattern as shown in Table 1. Structural transformation is necessary because every standard has its own structural format derived from the reference model by applying development rules; therefore it is necessary for correct parsing of the document. Some of ontology alignment and transformation patterns used for transformation purpose are explained in detail as follows:

Table 2 HL7 CDA and vMR Systolic and Diastolic Blood Pressure Observation

CDA Snippet (a)	vMR Snippet (b)
<component typeCode="COMP" contextConductionInd="true">	<observationResults>
<section classCode="DOCSECT" moodCode="EVN">	<observationResult>
<entry typeCode="COMP" contextConductionInd="true">	<templateId root="2.16.840.1.113883.10.20.1.32"/>
<observation classCode="OBS" moodCode="EVN">	<id root="107c2dc0-67a5-11db-bd13-0800200c9a66"/>
<code code="ObservationType"	<relatedClinicalStatement>
codeSystem="getCodeSystem"/>	<observationResult>
<entryRelationship typeCode="CAUS"	<templateId root="2.16.840.1.113883.10.20.1.31"/>
contextConductionInd="true">	<id root="33d27880-eb74-11e0-9572-0800200c9a66"/>
<observation classCode="OBS" moodCode="EVN">	<observationFocus displayName=" Systolic BP"
<code code="271649006" displayName="Systolic BP"	codeSystem="2.16.840.1.113883.6.96"
codeSystem="2.16.840.1.113883.6.96"	code=" 271649006"/>
codeSystemName="SNOMED CT"/>	<observationEventTime low=" 20080220102200+0300"
<effectiveTime xsi:type="IVL_TS">	high=" 20080220102200+0300"/>
<low inclusive="true" value="20080220102200+0300"/>	<observationValue>
<high inclusive="true" value="20080220102200+0300"/>	<physicalQuantity value=" 127 " unit=mm[Hg]"/>
</effectiveTime>	</observationValue>
<value xsi:type="PQ" value="127" unit="mm[Hg]"/>	</observationResult>
</observation>	</relatedClinicalStatement>
</entryRelationship>	<relatedClinicalStatement>
<entryRelationship typeCode="COMP"	<observationResult>
contextConductionInd="true">	<templateId root="2.16.840.1.113883.10.20.1.31"/>
<observation classCode="OBS" moodCode="EVN">	<id root="33d27880-eb74-11e0-9572-0800200c9a66"/>
<code code="271650006" displayName="Diastolic BP"	<observationFocus displayName=" Diastolic BP
codeSystem="2.16.840.1.113883.6.96"	codeSystem="2.16.840.1.113883.6.96"
codeSystemName="SNOMED CT"/>	code=" 271650006"/>
<effectiveTime xsi:type="IVL_TS">	<observationEventTime low=" 20080220102200+0300"
<low inclusive="true" value="20080220102200+0300"/>	high=" 20080220102200+0300"/>
<high inclusive="true" value="20080220102200+0300"/>	<observationValue>
</effectiveTime>	<physicalQuantity value=" 79 "unit=mm[Hg]"/>
<value xsi:type="PQ" value="79" unit="mm[Hg]"/>	</observationValue>
</observation>	</observationResult>
</entryRelationship>	</relatedClinicalStatement>
</observation>	</observationResult>
</entry>	</observationResults>
</section>	
</component>	

Sequence constraint pattern

Healthcare standards follow sequence by following reference model specifications. A CDA and vMR standard will follow particular sequence for recording patient observations while a slightly different when recording patient procedure related information. This information is identified and represented in the *MBO* by **Sequence Constraint Pattern** and is categorized under **Customized Bridge** class. Figure 4 shows this pattern by relating Customized Bridge class with mapping sequences of different standards. The sequences of standards are represented by **MappedSequences** class and are related with **CustomizedBridge** class through **hasParticipatingSequences** object property. The **MappedSequences** class individuals **Standard1** and **Standard2** follow some sequence and are related through **hasInputSequence** and **hasOutputSequence** object properties with **List_Standard1** and **List_Standard2** classes respectively. These lists contain sequences by using internal pattern called OWL List pattern proposed by N. Drummond [40]. N. Drummond [40] provided the detailed description of OWL List design pattern. **OWLList** class has object property **hasListProperty** and the end of the list is indicated by **EmptyList** class. The object property **hasListProperty** consists of two child object properties: **isFollowedBy** transitive property that is a super property of **hasNext** functional property and **hasContents** functional property. This defined the whole sequence with each item that is part of the list having one **hasContents** and one **hasNext** item. The transitive property **isFollowedBy** creates the linked chain of the sequence of items [40]. This pattern is used in our **Sequential Constraint Pattern** that is shown in Fig. 5.

The realization of Sequential Constraint Pattern is shown in Fig. 5 by showing vMR and CDA patient observations recording sequence. CDA consist of *Component* > *Section* > *Entry* > *Observation* > *EntryRelationship* sequence of classes for generating patient observation document where symbol '>' reflects followed by class. On the other hand, vMR follows *ObservationResults* > *ObservationResult* > *RelatedClinicalStatement* sequence of classes for representing the same observation information of CDA in vMR document. The list information in the specified sequence is stored in **List_CDA** and **List_VMR** classes. Their mapping information is maintained by **MappedSequences** class which is related with the **CustomizedBridge** class. While transformation, once the sequence of CDA is identified, it's converted into the sequence of classes of vMR and vice versa.

Overlap pattern relationship model

HL7 CDA consists of classes in the form of triplet "class-attribute-value". Attributes are divided into mandatory and optional categories. Therefore, while transformation of concepts between vMR and CDA these mandatory attributes

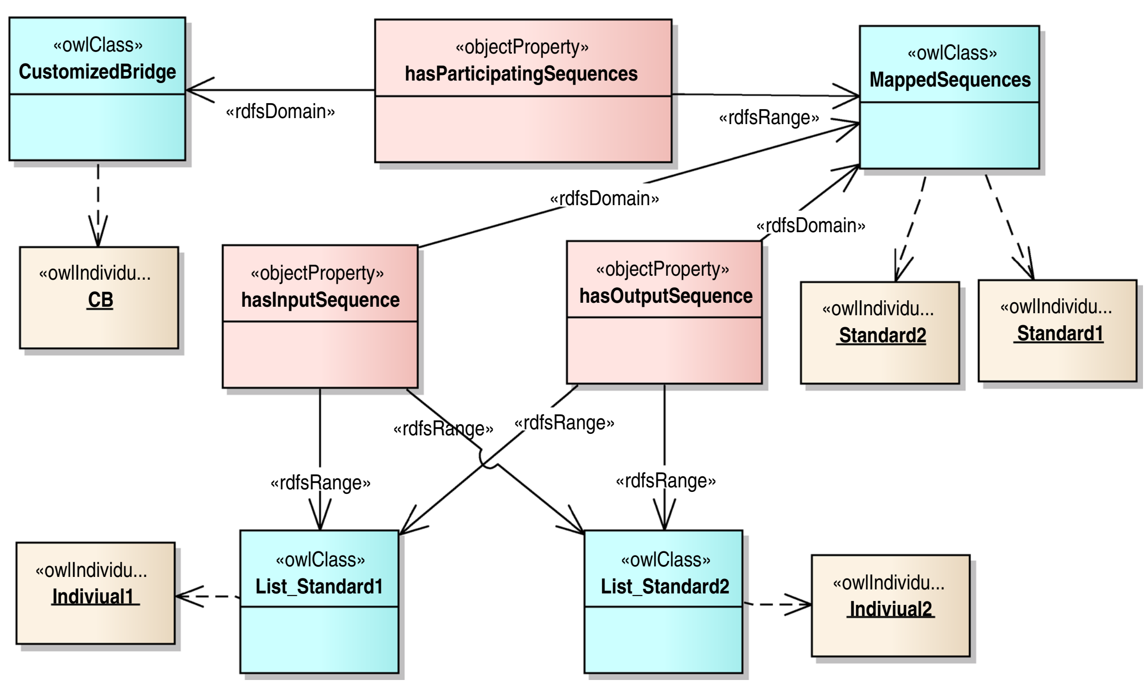

Fig. 4 Sequence Constraint Pattern

```
<rdf:RDF xmlns:vmr="http://www.owl-ontologies.com/VMR.owl#"
     xmlns:cda="http://www.owl-ontologies.com/CDA.owl#">
    <owl:Ontology rdf:about="BridgeOntology"/>
    <!-- Defining Classes for Sequence Constraint Pattern -->
    <owl:Class rdf:ID="CustomizedBridge"/>
    <CustomizedBridge rdf:ID="CustomizedBridgeInd">
        <hasParticipatingSequence rdf:resource="#MappedSequenceInd"/>
    </CustomizedBridge>
    .....
    <!-- OWL List Design Pattern -->
    .....
    <owl:ObjectProperty rdf:ID="hasInputSequence">
        <rdf:type rdf:resource="&owl;FunctionalProperty"/>
        <rdfs:domain rdf:resource="#MappedSequence"/>
        <rdfs:range>
            <owl:Class>
                <owl:unionOf rdf:parseType="Collection">
                    <owl:Class rdf:about="#List_CDA"/>
                    <owl:Class rdf:about="#List_VMR"/>
                </owl:unionOf>
            </owl:Class>
        </rdfs:range>
    </owl:ObjectProperty>
    <owl:ObjectProperty rdf:ID="hasOutputSequence">
        <rdfs:domain rdf:resource="#MappedSequence"/>
        <rdfs:range>
            <owl:Class>
                <owl:unionOf rdf:parseType="Collection">
                    <owl:Class rdf:about="#List_CDA"/>
                    <owl:Class rdf:about="#List_VMR"/>
                </owl:unionOf>
            </owl:Class>
        </rdfs:range>
    </owl:ObjectProperty>
    <owl:ObjectProperty rdf:ID="hasParticipatingSequence">
        <rdfs:domain rdf:resource="#CustomizedBridge"/>
        <rdfs:range rdf:resource="#MappedSequence"/>
    </owl:ObjectProperty>
    <owl:Class rdf:ID="List_CDA">
     <rdfs:subClassOf rdf:resource="&owl;Thing"/>
      <rdfs:subClassOf>
        <owl:Class>
         <owl:intersectionOf rdf:parseType="Collection">
          <owl:Restriction>
           <owl:onProperty rdf:resource="#hasContents"/>
            <owl:someValuesFrom rdf:resource="&cda;Component"/>
           </owl:Restriction>
           <owl:Restriction>
            <owl:onProperty rdf:resource="#hasNext"/>
             <owl:someValuesFrom>
              <owl:Class>
               <owl:intersectionOf rdf:parseType="Collection">
                <owl:Restriction>
                 <owl:onProperty rdf:resource="#hasContents"/>
                 <owl:someValuesFrom rdf:resource="&cda;Section"/>
                </owl:Restriction>
......
<!-- Sequence of CDA in this example after Section
is Entry,Observation and Entry Relationship Classes -->
......
    </owl:Class>
  </rdfs:subClassOf>
</owl:Class>
<List_CDA rdf:ID="List_CDAInd"/>
<owl:Class rdf:ID="List_VMR">
 <rdfs:subClassOf rdf:resource="&owl;Thing"/>
 <rdfs:subClassOf>
  <owl:Class>
   <owl:intersectionOf rdf:parseType="Collection">
    <owl:Restriction>
     <owl:onProperty rdf:resource="#hasContents"/>
     <owl:someValuesFrom rdf:resource="&vmr;ObservationResults"/>
    </owl:Restriction>
    <owl:Restriction>
        <owl:onProperty rdf:resource="#hasNext"/>
        <owl:someValuesFrom>
            <owl:Class>
 .....
   <!-- Sequence of VMR in this example after
   Observation Results is Observation Result,
   and Related Clinical Statement Classes -->
.....
</owl:Class>
<List_VMR rdf:ID="List_VMRInd"/>
<owl:Class rdf:ID="MappedSequence"/>
<MappedSequence rdf:ID="MappedSequenceInd">
    <hasOutputSequence rdf:resource="#List_VMRInd"/>
    <hasInputSequence rdf:resource="#List_CDAInd"/>
</MappedSequence>
</rdf:RDF>
```

Fig. 5 Sequence Constraint Pattern

transformation is necessary for correct parsing of the document. Overlap Pattern Relationship Model deals with such type of patterns where source standard concept with its mandatory attributes and values is converted into target concept. In this type of pattern an ontology O_i consist of class C_i with mandatory attributes MA_i having values V_i is mapped with class C_i of another ontology O_j. This pattern is categorized under Overlap Bridge of the *MBO* because of the overlapping behavior between matching concepts as shown in Fig. 6.

The pattern for Overlap Bridge is shown in Fig. 6. **OverlapBridge** class has relationship with **Standard1Class** and **Standard2Class** through **hasSourceClass** and **hasTargetClass** object properties respectively. **OverlapBridge** class is related with **Match** class using **hasRelationship** object property with individuals **Exact** or **Subsume**. There are cases in which mandatory properties of both the standards are exactly matched while in some cased source concept has subsumption relationship with target concept. **Standard1Class** and **Standard2Class** are also related with each other using **hasSameRelationship** object property. **Standard1Class** consists of **MandatoryAttributes** connected by **consistMandatoryAttributes** object property and these **MandatoryAttributes** contains some values represented by **hasValue** data type property. The realization of this pattern is given in Fig. 7.

We explained **Overlap Pattern Relationship Model** with **EntryRelationship** concept of CDA standard with **RelatedClinicalStatement** concept of vMR concept as shown in Fig. 7. **EntryRelationship** class of HL7 CDA has mandatory attributes such as **typeCode** and **contextConductionInd** with values **CAUS** and **true** respectively. This information is mapped with **RelatedClinicalStatement** class of vMR, therefore translation of **RelatedClinicalStatement** class is performed with **EntryRelationship** class and its mandatory attributes and values.

Evaluation

We have evaluated ARIEN system on datasets of Diabetes and Cancer patients encounter information gathered from local hospitals. The scenario of HMIS complaint to CDA and CDSS compliant to vMR is continued in this section. When the HMIS wants to query CDSS for guideline provision, the information is provided in CDA format. The CDSS can only process the information when it is in vMR Input format. So conversion from CDA to vMR Input is

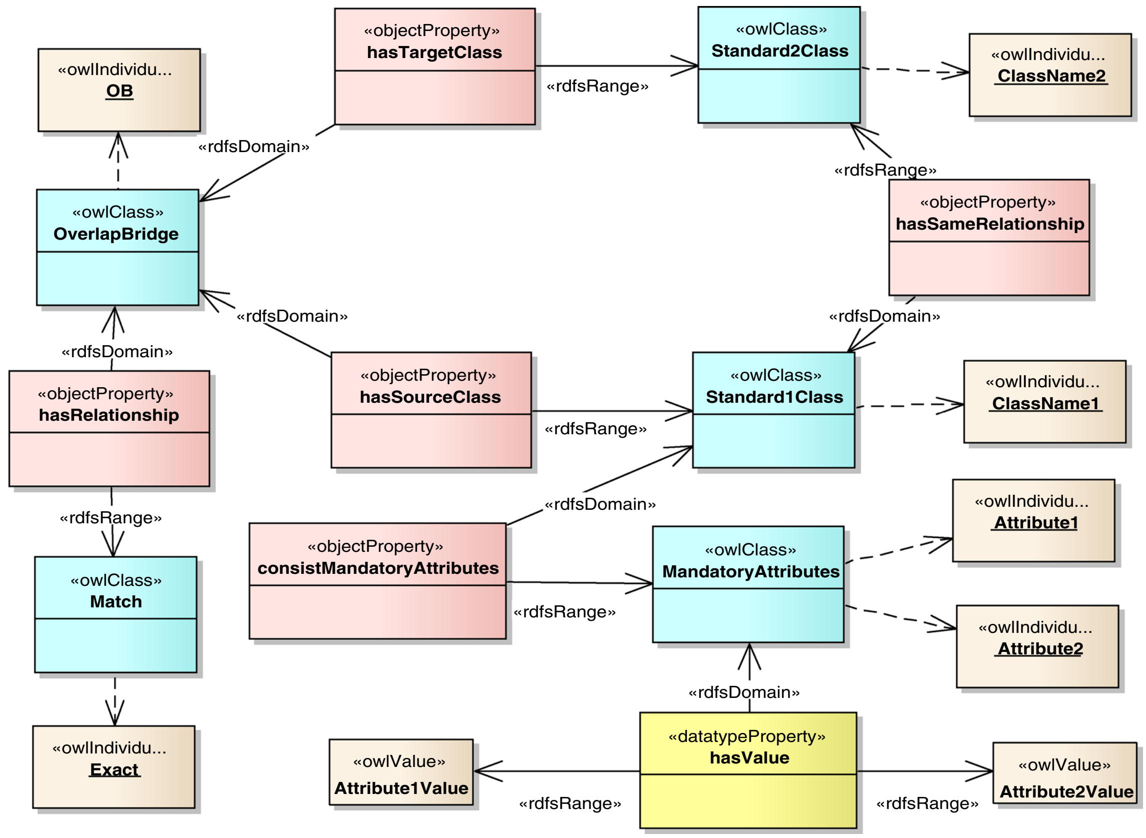

Fig. 6 Overlap Pattern Relationship Model

performed by ARIEN system. CDSS process the information and generates guidelines in the form of vMR Output. This vMR Output is not understandable format for HMIS therefore conversion from vMR Output to CDA is again performed by ARIEN system. The experiments are conducted by converting CDA to vMR Input and vMR Output to CDA

```
<rdf:RDF
 xmlns:vmr="http://www.owl-ontologies.com/VMR.owl#"
 xmlns:cda="http://www.owl-ontologies.com/CDA.owl#">
 <owl:Ontology rdf:about="BridgeOntology"/>
 <!-- Defining Classes for Class Mandatory Attributes Value
 to Class Matching Pattern -->
   <owl:Class rdf:ID="OverlapBridge"/>
   <owl:Class rdf:ID="MandatoryAttributes"/>
   <owl:Class rdf:ID="Match"/>
   <owl:Class rdf:ID="Standard1Class"/>
   <owl:Class rdf:ID="Standard2Class"/>
 <!-- Object Properties -->
    <owl:ObjectProperty rdf:ID="consistMandatoryAttributes">
     <rdfs:domain rdf:resource="#Standard1Class"/>
     <rdfs:range rdf:resource="#MandatoryAttributes"/>
    </owl:ObjectProperty>
    <owl:ObjectProperty rdf:ID="hasRelationship">
     <rdfs:domain rdf:resource="#OverlapBridge"/>
     <rdfs:range rdf:resource="#Match"/>
    </owl:ObjectProperty>
    <owl:ObjectProperty rdf:ID="hasSameRelationship">
     <rdfs:domain rdf:resource="#Standard1Class"/>
     <rdfs:range rdf:resource="#Standard2Class"/>
    </owl:ObjectProperty>
    <owl:ObjectProperty rdf:ID="hasSourceClass">
     <rdfs:domain rdf:resource="#OverlapBridge"/>
     <rdfs:range rdf:resource="#Standard1Class"/>
    </owl:ObjectProperty>
    <owl:ObjectProperty rdf:ID="hasTargetClass">
     <rdfs:domain rdf:resource="#OverlapBridge"/>
     <rdfs:range rdf:resource="#Standard2Class"/>
    </owl:ObjectProperty>
 <!-- CDA Class with its mandatory attributes and values -->
    <Standard1Class rdf:ID="CDA_EntryRelationship">
     <hasSameRelationship rdf:resource=
     "#RelatedClinicalStatement"/>
     <consistMandatoryAttributes rdf:resource="#TypeCode"/>
     <consistMandatoryAttributes rdf:resource=
     "#ContextConductionInd"/>
    </Standard1Class>
    <owl:DatatypeProperty rdf:ID="hasValue">
     <rdfs:domain rdf:resource="#MandatoryAttributes"/>
     <rdfs:range rdf:resource="&xsd;string"/>
    </owl:DatatypeProperty>
    <MandatoryAttributes rdf:ID="ContextConductionInd">
     <hasValue rdf:datatype="&xsd;string">true</hasValue>
    </MandatoryAttributes>
    <MandatoryAttributes rdf:ID="TypeCode">
     <hasValue rdf:datatype="&xsd;string">CAUS</hasValue>
    </MandatoryAttributes>
    <Match rdf:ID="Exact"/>
 <!-- VMR Class -->
    <Standard2Class rdf:ID="VMR_RelatedClinicalStatement"/>
 <!-- Overlap Bridge Relationship -->
    <OverlapBridge rdf:ID="OverlapBridgeInd">
     <hasSourceClass rdf:resource="#EntryRelationship"/>
     <hasRelationship rdf:resource="#Exact"/>
     <hasTargetClass rdf:resource="#RelatedClinicalStatement"/>
    </OverlapBridge>
</rdf:RDF>
```

Fig. 7 Overlap Pattern Relationship Model (CDA and vMR Example) and the detailed description of the results are provided as follows:

Accuracy of mappings in transformation process

CDA to vMR input conversion

The portion of the CDA document that is most related with vMR document is CDA body part. This part contains the patient observations details which requires processing by CDSS for recommendations or guidelines generation. Therefore, we observed smooth transformation process, as the number of vMR transformation constructs are subset of CDA transformation constructs. Also, this type of conversion mechanism is used for generation of *vMR Input* record from the CDA. The result of mapping constructs (concepts, attributes, and their values) precision, recall, and f-measure in the transformation process from CDA to vMR Input record is shown in Table 3 (Table for Precision, Recall, F-Measure (a)) and graph (Graph for Precision, Recall, F-Measure (b)) formats. Accuracy is measured by using the formula

Accuracy = [True Positives (TP) + True Negatives (TN)] / [True Positives (TP) + True Negatives (TN) + False Positives (FP) + False Negatives (FN)]

There are no false positives and true negatives in the transformation process therefore the precision of concepts, attributes and values is 1. Initially, we considered only SPHeRe's mappings generated and stored in *MBO*. The recall of these mapping constructs lies between 0.75 and 0.8 therefore approximately 0.877 is the overall F-Measure. The only concepts that are not properly transformed include **ClinicalStatementRelationships** and its sub-concepts, their attributes and values. This is because the mappings for these mappings constructs were not stored in the *MBO* as the SPHeRe matching systems of Accuracy Mapping Engine was unable to find suitable corresponding mapping concept in CDA. The overall accuracy achieved in this case is 79 %. The concept **ClinicalStatementRelationships** and its sub-concepts,its attributes were identified with P-DCM approach by involving conformance information. The overall accuracy has improved to 93 % with the only the values of the attributes of **ClinicalStatementRelationships** remained unresolved. A strategy to resolve this problem is discussed in section "Discussion" that will further increase the level of accuracy.

Organization specific conformance information is stored in P-DCM ontology. This information is used to generate customized mappings that have contributed in the overall increase in accuracy level from 79 % to 93 %. Therefore, organization conformance information handling is necessary for generating customized mappings to support generalized mappings for complete data interoperability.

VMR output to CDA conversion

The vMR Input is processed by CDSS to generate recommendations/guidelines in vMR Output format. The format of guidelines is not compatible with HMIS therefore vMR Output conversion to CDA format is required. The information of vMR Output is mapped with CDA body portion completely; however, there exists mapping constructs in CDA that are necessary for parsing document. These constructs are handled by structural mappings but transformation is faced with the values assignment problem. Values to the concepts and their attributes that are transformed using structural mappings cannot be assigned automatically. We provided a solution to this problem by involving human interventions. The details of the results of conversion process without human intervention are provided in Table 4.

Table 3 CDA to vMR Input Transformation Process Results

Table for Precision, Recall, F-Measure (a)

	Precision	Recall	F-Measure
Concepts	1	0.767	0.867
Attributes	1	0.799	0.888
Values	1	0.799	0.888

Overall Accuracy = 79%
(*MBO* Mappings with SPHeRe)

	Precision	Recall	F-Measure
Concepts	1	1	1
Attributes	1	1	1
Values	1	0.799	0.888

Overall Accuracy = 93%
(*MBO* Mappings with SPHeRe and P-DCM Approach)

Graph for Precision, Recall, F-Measure (b)

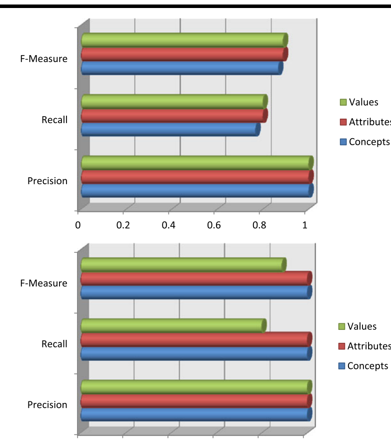

Table 4 VMR Output to CDA Transformation Process Results

Table for Precision, Recall, F-Measure (a)

	Precision	Recall	F-Measure
Concepts	1	1	1
Attributes	1	1	1
Values	1	0.856	0.922

Overall Accuracy = 95%

Graph for Precision, Recall, F-Measure (b)

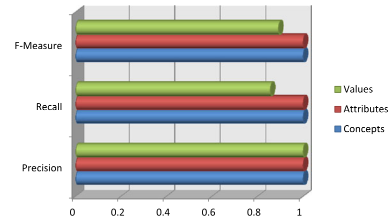

Table 4 (Table for Precision, Recall, F-Measure (a)) and graph (Graph for Precision, Recall, F-Measure (b)) shows the precision, recall and f-measure for concepts, attributes and their values conversion as shown in Table 4. Unlike CDA to vMR Input conversion, this type of conversion has precision, recall, and f-measure equal to 1 for concepts and attributes except values. The values recall and f-measure are 0.856 and 0.922 respectively. The overall accuracy for transformation process is 95 %. The only problem of values transformation at run-time is faced because of the structural mappings transformation process in which values cannot be automatically converted due to lack of information and human interventions becomes inevitable. If the values to these concepts are provided beforehand the conversion process shows 100 % conversion result. As vMR output only contain recommendations and it uses less concepts than vMR input therefore, generalized mappings transform vMR ouput to CDA with 95 % accuracy having no need of customized mappings.

Discussion

The proposed system transformation process performs structural mappings, sequential mappings, and data transformation mappings as explained in the previous sections. These mappings involve transformation mapping constructs (concept, attributes/properties and their values) conversion between different standards format. The more the mappings are stored in the *MBO*, the accurate and more complete will be the transformed format. We faced some challenges in the mapping process, the detail of their cause and our solution are the focus of this section. The discussion is based on the level of transformation from vMR to CDA format.

Table 5 Author and Custodian Concepts Information in CDA

Author Class (a)

```
<author>
 <time value=""/>
 <assignedAuthor>
 <id extension="" root=""/>
 <addr>
 <streetAddressLine/>
 <city/>
 <postalCode/>
 <country/>
 </addr>
 <assignedPerson>
 <name>
 <given/>
 <family/>
 <suffix/>
 </name>
 </assignedPerson>
 </assignedAuthor>
</author>
```

Custodian Class (b)

```
 <custodian>
 <assignedCustodian>
<representedCustodianOrganization>
<id root=""/>
<name/>
<telecom value="tel:" use=" "/>
<addr>
<streetAddressLine/>
<city/>
<postalCode/>
<country/>
</addr>
</representedCustodianOrganization>
</assignedCustodian>
</custodian>
```

The vMR to CDA conversion process involves the transformation mapping constructs of *vMR Output*. The *vMR Output* consists of the guidelines or recommendations generated for patients after processing by the CDSS. In this case the number of transformation mapping constructs in vMR is less while due to some structural transformations requirements CDS transformation mapping constructs are more. The problem occurs only in the value assignments stage for particular attributes of concepts that are part of the structural mappings transformation process. Table 5 shows *Author* and *Custodian* classes of CDA standard that are necessary for parsing the CDA document. In CDA RMIM *"an author is a person in the role of an assigned author (AssignedAuthor class). The entity playing the role is a person (Person class) or a device (AuthoringDevice class)"* [17]. On the other hand, *"Custodian represents the organization that is in charge of maintaining the document. Every CDA document has exactly one custodian"* [17]. These classes values while conversion from vMR Output to CDA are performed by structural mappings but the Author class values for attributes time, address, city, assignedPerson name, and other (as shown in Table 5a) and also Custodian class values for attributes id, name, address and others (as shown in Table 5b). The solution to this problem is before vMR Output to CDA conversion, human intervention is made and these particular attribute values are asked by the system to manually enter for conversion to CDA format. In this way with minimal human interventions, maximum accuracy of the transformation process is achieved for true data interoperability among communicating HISs. The accuracy of the transformation process is directly related to the mappings stored and also their representation. If the mappings stored consist of more annotated information then the challenges can be easily handled in conversion process. Some concepts can map with multiple concepts, their identification and transformation is performed in our case by utilizing the annotated information stored with the matched concepts in the *MBO*. **ObservationFocus** attribute in vMR can be mapped with **code** and **title** attribute of CDA. Therefore, in **title** and **observationFocus** mapping, hierarchy information is annotated for conversion. This type of concept to multiple concepts mappings are handled by annotating parent information with concept. So, in CDA to vMR transformation, **title** attribute can only be converted to **observationFocus** when hierarchy when the parent class of title attribute exists in the stored mapping, otherwise **code** attribute of CDA will map with **observationFocus** attribute of vMR.

Conclusion

Data interoperability is the key factor for seamless information exchange among HISs. The proposed system achieves data interoperability by providing mediation services for accurate transformation process of medical records between HL7 CDA and vMR standards. Transformation process is dependent on the mappings stored therefore we applied ontology matching techniques to identify and store accurate mappings for ensuring higher level of transformation process accuracy.

Conformance issues of organizations with specific concepts in different standards invalidate some of the mappings stored in the *MBO*. Therefore, change management techniques needs to be practiced to ensure continuity of mappings. The continuity of mappings complements the accuracy of mappings and is future work of the proposed ARIEN system. Accuracy and continuity of mappings will ensure true data interoperability among HISs.

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