AdapteR Interoperability ENgine (ARIEN): An approach of Interoperable CDSS for Ubiquitous Healthcare

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Abstract. Information exchange for interoperability between medical systems and clinical decision support systems (CDSS) is a challenging task to provide personalized healthcare services. Healthcare standards behaves as catalyst for interoperability and plays important role in ubiquitous healthcare. Heterogeneity among these standards creates bottleneck for decision support systems to easily integrate with legacy medical systems. Medical systems and CDSS standards compatibility requires mediation process to ensure seamless information exchange. We propose such mediation system between medical systems and CDSS called AdapteR Interoperability ENgine (ARIEN) to achieve data level interoperability. We consider information flow from smart homes and medical systems in HL7 Clinical Document Architecture (CDA) format with CDSS compliant to Virtual Medical Record (vMR) standard. The responsibility of the proposed system is transformation of smart homes and medical systems compliant standard format information into CDSS compliant standard format for processing of information and vice versa. This work achieves information exchange compatibility among systems for providing better healthcare to patients. It also ensures availability of required information at the specified time for ubiquitous healthcare.

Keywords: CDSS, HL7, HMIS, Interoperability, Ontology.

1 Introduction

Evolution of healthcare standards has contributed in achieving the goal of interoperability among medical systems. Clinical Decision Support System (CDSS) design and development is one of the progressing area to use healthcare standards for ubiquitous healthcare. Standard based CDSS systems exists in the literature that provide benefits like scalability, easy for data sharing and flexibility. One such initiative is taken in our lab [1] that is called as Smart CDSS.

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

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Smart CDSS is standard based clinical decision system that provides recommendations to physicians and patients based on the heterogeneous data sources including clinical data, social media data, behavior modeling data and activities and emotion recognition data [5] [4]. Among its different features, interoperability of medical systems and smart homes compliant to different standards with Smart CDSS is a key challenge. This kind of interoperability is considered as 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 [10]. This challenge can be resolved by resolving heterogeneities between different heterogeneous healthcare standards.

Smart CDSS consumers include systems that are compliant to different healthcare standards (HL7 V3, CDA, openEHR or CEN 13606). Smart CDSS can only process information in Virtual Medical Record (vMR) standard. Therefore, an adapter is required to transform HMIS compliant healthcare standard to Smart CDSS compliant healthcare standard and vice versa. We propose an adapter called Adapter Interoperability Engine (ARIEN) that facilitates Smart CDSS in achieving interoperability with different medical systems and smart homes. Ontology matching technique is used to achieve interoperability between these legacy systems and Smart CDSS.

We are considering HL7 CDA standard for medical systems and smart homes compliancy and developed HL7 CDA and vMR ontologies based on their specifications. Ontology matching techniques are applied to find out appropriate mappings between the two standards. Also, changes can evolve into standards, therefore the proposed system also monitors any changes in the standard to be reflected in the mapping file repository called *Mediation Bridge Ontology (MBO).* This adds to the accuracy of mappings in the form of continuity of mappings. This leads to removing heterogeneities among standards and allow interoperable communication between systems.

2 Smart CDSS as a Service

Smart CDSS is an initiative taken by our lab, to provide recommendations to physicians and patients based on heterogeneous data sources. The different modules of Smart CDSS as shown in Figure 1 consists of:

- Adaptability Engine, used for obtaining data from different sources and transforming it into standard vMR format.
- Interface Engine, used as a communication medium between Adaptability Engine and Knowledge Inference Engine.
- Knowledge Inference Engine, used to perform reasoning on the input information to provide recommendations.

The different data sources provides information to Smart CDSS through Adaptability Engine. These data sources consists of clinical data, social media data, activities recognition data, and behavior modeling data of the patient.

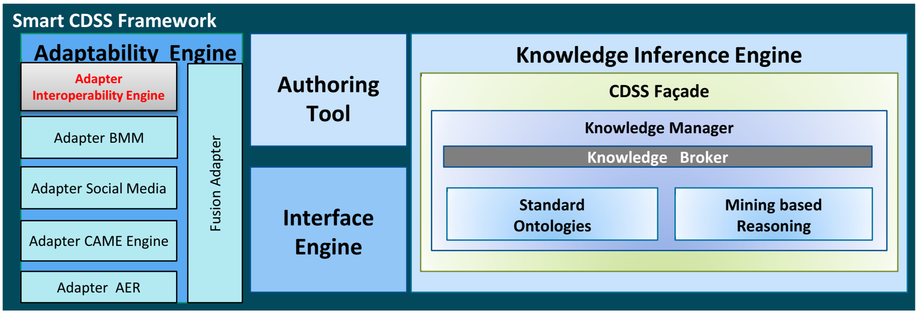

Fig. 1. Architecture of Smart CDSS

Adapter Behavior Modeling Module (BMM) is used for monitoring and obtaining the behavior modeling information of the patient. The Social Media Adapter is used for observing patient social media interaction activities such as twitter. Adapter CAME Engine is used for providing information of patients activities by converting low level sensory information to high level context aware information. Activity and Emotion Recognition (AER) Adapter is used to recognize patient activities and emotions in daily life. Clinical data is handled by ARIEN, that is used for converting one standard format to another, in this case conversion between vMR and CDA. Finally the Fusion Adapter is used to concatenate all the vMR's from different data sources into a single vMR. The proposed system ARIEN is the focus of this paper that provides interoperability services for systems compliant to different standards for using standard based Smart CDSS.

3 Related Work

Existing systems in literature highlights the importance of interoperability for CDSS systems. The role of ontologies becomes more important in the path towards interoperable CDSS. This is highlighted in [1], 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 intelligent decision support system to improve patient lifecare by monitoring their activities. It depends on semantically enriched web services for communicating information to tackle interoperability [3]. Other than decision support systems, there are other systems that work on interoperability aspects among different standards. Prominent work in literature with interoperability as objective among different healthcare standards include: Artemis (semantic mediation between different Health Information Systems (HIS)) [2], PPEPR (resolving heterogeneity between HL7 v2 and v3) [11], LinkEHR (tool used for transformations among standards such as HL7, openEHR and CEN 13606) [8], and Poseacle Converter (CEN 13606 and openEHR standards archetypes and extracts transformation and validation) [9]. Finally, we also have worked on process interoperability among different HISs compliant to HL7 standard having heterogeneous workflows [7]. All the existing systems mentioned above contributed in achieving interoperability among healthcare systems but focuses only on transformation aspects. Our proposed system works handles accuracy of mappings, continuity of mappings for standard format transformations.

4 Proposed Architecture

The proposed system is divided into three primary modules: *Accuracy Mapping Engine*, *Standard Ontology Change Management* and *Transformation Engine* as shown in Figure 2 and described in detail as follows:

4.1 Accuracy Mapping Engine

This component deals with the generation of ontology mappings. CDA and vMR ontologies developed are mapped using ontology matching techniques such as string based, child based, property based and label based matching techniques. These matching techniques are used by our matching system called ***S**ystem for **P**arallel **He**terogeneity **Re**solution SPHeRe*[2]. *SPHeRe* takes as input the source and target ontologies for matching and the mappings generated are stored in *MBO*. *MBO* behaves as a mapping file repository for storage of mappings. Another approach that we use for increasing the accuracy of mappings is *Personalized-Detailed Clinical Model (P-DCM)* [6] approach. P-DCM approach uses organizational conformance information to improve accuracy level of the mappings stored in the *MBO.P-DCM* and *Expert Verifications* improves the overall accuracy of the mapping file. Standards can evolve with the passage of time by accommodating new changes, therefore requiring continuity of mappings of *MBO*.

4.2 Standard Ontology Change Management

Standard Ontology Change Management component is responsible for reflecting the changes in the mappings generated that are necessary after change occurs in any or both source and target ontologies. *Change Detector* always listens for any change in the mapping ontologies. The change information is accessed by *Change Collector* once that change is detected by *Change Detector*. This information is then provided to *Change Formulator* for converting the changes into processable format. Matching of only the changes with the target ontology is carried out and reflected in the already stored mappings in the form of updation.

4.3 Transformation Engine

Transformation Engine component performs the conversion of standard formats by communicating with the HMIS. *Communication Content Handler* access information from the HMIS in HL7 CDA format and forwards it to *Conversion*

[2] `http://uclab.khu.ac.kr/sphere`

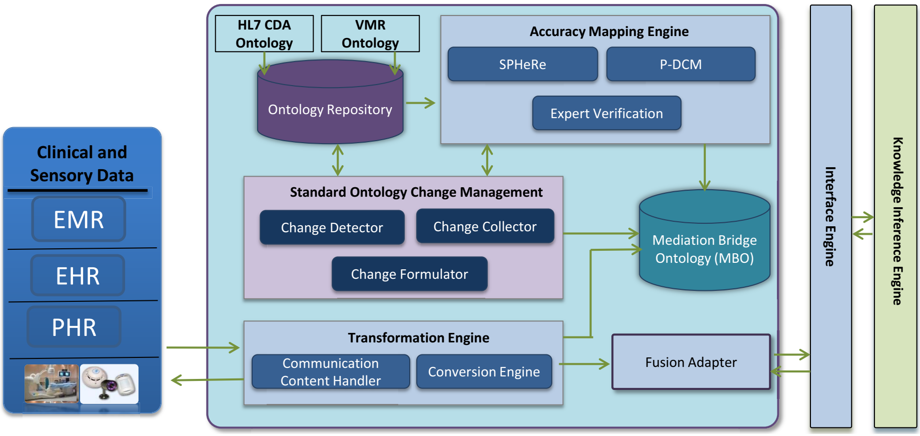

Fig. 2. ARIEN Proposed Architecture

Engine. *Conversion Engine* uses mappings from *MBO* to convert from HL7 CDA standard format to vMR format for Smart CDSS to process and generate guidelines. In the same way when the guideline are to be provided to HMIS, conversion from vMR to CDA format is performed.

5 Working Scenario

Two steps define the working process of the proposed ARIEN system. Firstly, offline approach includes development of standards ontologies such as CDA and vMR, then generating mappings between them and storing in the *MBO*. Secondly, legacy systems using services of Smart CDSS through ARIEN. This section explains the working model of proposed system.

In this scenario, we assume that smart homes and medical systems are compliant to HL7 CDA standard. Figure 3 shows snippet of HL7 CDA showing patient information from smart home collected using smartphone about his/her sleeping behavior. The information reflects that the patient was having difficulty in sleep as suggested by observation values. Once this information is obtained by ARIEN, Communication Handler passes it to Conversion Engine for conversion into Smart CDSS processable format, vMR.

Conversion Engine access the mapping information from the *MBO* for conversion process to vMR format. Different design patterns are used for alignments creation and storage of mappings in the *MBO*. Classes, properties and values are accessed and their alternative concepts are searched in the *MBO* for translation from one standard format to another. Figure 4 shows the **Overlap Pattern Relationship Model** pattern that has been used for creation of mapping between classes of different ontologies with attribute values. In this case, **Observation** class of HL7 CDA has mandatory attributes such as **classCode** and **moodCode**

```
<observation classCode="OBS" moodCode="EVN">
    <code code="301345002" codeSystem="2.16.840.1.113883.6.96"
    codeSystemName="SNOMED CT" displayName="Difficulty sleeping (finding)"/>
    <effectiveTime xsi:type="IVL_TS">
        <low inclusive="true" value="20080220102200+0300"/>
        <high inclusive="true" value="20080220102200+0300"/>
    </effectiveTime>
</observation>
```

Fig. 3. HL7 CDA: Difficulty Sleeping Observation

```
<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 Overlap Bridge -->
    <owl:Class rdf:ID="OverlapBridge"/>
    <owl:NamedIndividual rdf:ID="OverlapBridgeInd">
        <rdf:type rdf:resource="#OverlapBridge"/>
        <hasRelationship rdf:resource="#Exact"/>
    </owl:NamedIndividual>
    <owl:Class rdf:ID="Standard1Class"/>
    <owl:Class rdf:ID="Standard2Class"/>
    <owl:Class rdf:ID="MandatoryAttributes"/>
    <owl:Class rdf:ID="Match"/>
    <owl:ObjectProperty rdf:ID="consistMandatoryAttributes">
        <rdfs:domain rdf:resource="#Standard1Class"/>
        <rdfs:range rdf:resource="#MandatoryAttributes"/>
    </owl:ObjectProperty>
    <MandatoryAttributes rdf:ID="classCode">
        <hasValue rdf:datatype="&xsd;string">OBS</hasValue>
    </MandatoryAttributes>
    <MandatoryAttributes rdf:ID="moodCode">
        <hasValue rdf:datatype="&xsd;string">EVN</hasValue>
    </MandatoryAttributes>
    <owl:NamedIndividual rdf:ID="Exact">
        <rdf:type rdf:resource="#Match"/>
    </owl:NamedIndividual>
    <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>
    <owl:DatatypeProperty rdf:ID="hasValue">
        <rdfs:domain rdf:resource="#MandatoryAttributes"/>
        <rdfs:range rdf:resource="&xsd;string"/>
    </owl:DatatypeProperty>
    <owl:NamedIndividual rdf:ID="Observation">
        <rdf:type rdf:resource="#Standard1Class"/>
    </owl:NamedIndividual>
    <owl:NamedIndividual rdf:ID="ObservationResult">
        <rdf:type rdf:resource="#Standard2Class"/>
    </owl:NamedIndividual>
</rdf:RDF>
```

Fig. 4. Overlap Pattern Relationship Model

with values **OBS** and **EVN** respectively. Now this information is mapped with **ObservationResult** class of vMR, therefore translation of **ObservationResult** class is performed with **Observation** class with its attributes and values. In the same way, **code** property of **Observation** class in CDA is mapped to **observationFocus** property of **ObservationResult** class in vMR standard as shown in Figure 5 using *Property Matching pattern*. In the same way other ontology matching patterns exists that are used for alignments generation and then used for transformation.

```
<observationResult>
    <observationFocus displayName="Difficulty sleeping (finding)"
    codeSystem="2.16.840.1.113883.6.96" code="301345002"/>
    <observationEventTime
    low=" 20080220102200+0300 " high=" 20080220102200+0300 "/>
</observationResult>
```

Fig. 5. HL7 vMR: Difficulty Sleeping ObservationResult

This converted vMR is passed to Fusion Adapter which forwards it to Knowledge Inference Engine through Interface Engine for processing and recommendation generation. The recommendations generated by Smart CDSS is again communicated through ARIEN with smart home by converting vMR to CDA format using *MBO*.

6 Conclusion

Ubiquitous healthcare requires data interoperability among medical systems and it is a vital factor for success of CDSS. The proposed systems provides the gateway to CDSS for achieving the goal of data interoperability using ontology matching. The two most important factors discussed in this paper for data interoperability are accuracy and continuity of mappings. Accuracy of mappings is dependent on continuity of mappings by handling change management.

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