Ontologising Interaction Behavior for Service-Oriented Enterprise Healthcare Integration

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Abstract

In this paper we analyse a healthcare standard (HL7) as an integration mechanism to connect service-oriented healthcare enterprises. Healthcare enterprises differ in their process model even if they follow same standard. This difference is due to the way in which healthcare is influenced by various stakeholders within regional clinical practices. Thus the design of the interaction behaviour (a.k.a. HL7 interactions) of communicating healthcare enterprises is subject to local implementation. We present a use case that shows how heterogeneous process models evolve, even if healthcare care institutes follow a particular standard such as HL7. We present an approach that enables the separation of the process layer to enable control and to resolve the heterogeneity of the enterprise interaction behavior (public & private). We apply semantics on top of HL7 profiles (e.g. Web-Service & SOA4HL7) to resolve ambiguity in the service and process definitions of HL7 compliant healthcare enterprises. We propose an integration platform called PPEPR: Plug and Play Electronic Patient Records, which is based on the principals of semantic Service-Oriented Architecture (sSOA). The use case, integration requirements, and approach presented in this paper are within the scope of the PPEPR project.

1. Introduction

Web services provide the technology foundation for implementing and delivering SOA platforms. In recent years various research and industrial efforts have focussed on Service-Oriented Architectures (SOAs) and Web service technology. The two core challenges of conventional computing - search and integration - (also known as semantic gap of SOA) are not addressed by SOAs. Therefore, SOA itself is not a complete solution for the integration of service-oriented enterprise information systems and success of Web services and SOA itself still depends on resolving three fundamental challenges, namely search, integration and mediation [3, 5, 18]. The integration and/or interoperability requirements of service-oriented enterprise information systems have resulted in the development of new breeds of SOAs, called semantic Service-oriented Architecture (sSOA) where this "semantic gap" is solved by applying ontologies on top of SOAs to resolve ambiguity in data and service definitions. Unfortunately, this "semantic gap" is not well defined for an enterprise integration solution. This is due to the fact that the size of the gap varies between domains and depends on the particular context where SOA based enterprise solutions are deployed. A generalised approach for all enterprises is not useful as each domain has its own complexities and interoperability requirements. A domain-based, balanced approach which includes domain knowledge (e.g. simple taxonomies, ontologies), technology (e.g. Web services, semantic tools), and domain specific development methodology (e.g. top-down/bottom-up) is required to achieve the full potential of a semantic Service-oriented architecture and to deliver a meaningful enterprise integration solution.

In this paper we analyse the integration requirements of
2. Healthcare, SOA, and Web-Service

In the year 2003 HL7 has published the HL7 version 3 Web service profile\(^1\) that provides the useful capability to transport existing HL7 v3 messages using Web service protocols. The intention of this WS profile is to achieve “plug-n-play” interoperability via Web services in a healthcare environment. In this environment Independent Software Vendors (ISV) and corporate developers implementing HL7 interfaces can write generic and reusable classes, subroutines, and modules consistent with the guidelines set forth by the HL7 for Web services standards in order to handle HL7 message traffic from a potentially unlimited number of connecting applications and services. If applications that “expose” HL7 messages follow the HL7 Web services profile (WSP) guidelines, then “consumers” of HL7 messages can be written without prior knowledge of interacting applications. Three major issues from an integration perspective are:

- The service definition becomes superfluous, this leads to message definition based bottom up approach where service clients are automatically able to interoperate based on the messaging definition.

- The WS-profile assumes that all different healthcare entities will follow the particular standard.

- Message, service, and process definitions are tied together. Thus, there is an absence of “separation of concern”.

One major benefit of this approach is that “prior knowledge” or a single “agreed” model is not required at the communication level but still assumes a single “agreed” model at specification level where all healthcare entities should follow the Web service profile. There is a common industrial practice that people who manage information, most often have different ways of interpreting it. For example, most of IT or healthcare professionals are open to different interpretation of medical standards and diverge from the standard intended meaning and use them for different purposes, thus challenging the purpose of industry standard.

Recently HL7 has published SOA4HL7\(^2\) a guideline for implementing healthcare services within a Service Oriented Architecture. SOA4HL7 complements the Service Specification Framework (SSF) defined within the Healthcare Services Specification Project (HSSP)\(^3\), but provides an additional interim method of defining and implementing Web services based on HL7 v3 artifacts. Two major integration issues are:

- The SOA4HL7 profile is intended to provide a top-down “service based” approach, which means that the service definition (or service contract) becomes key and needs to be available to the client at design time. This requires a single “agreed” service definition model, in the form of a fully approved industry standard specification.

- Even though the SOA4HL7 profile has separated the message definition from the service definition, a valuable input from the Healthcare Services Specification Project (HSSP), it still lacks the separation of the “processes” from the services. As, we discussed above this separation is important because each healthcare enterprise differs in their process model even if they follow same standard. In this regard, separation of interaction behavior (e.g. HL7 message exchange pattern (MEP)\(^4\), HL7 interactions) into a process (orchestration and/or choreography) layer is required to enable control and resolve the heterogeneity of interaction behavior. The focus of this paper is to present an approach for semantic description of interaction behavior. This behavioral semantics is the formal description which defines a service’s external (public) and internal (private) behavior. The external behavior describes a protocol that can be used by the client to consume the service functionality. The internal behavior describes a workflow, i.e. how the functionality of the service is aggregated out of other services [18]. In PPEPR, behavioral ontology has been developed for semantic description of service’s

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7. http://www.w3.org/TR/wsd120-adjuncts/#meps
A detailed description of HL7 profiles is outside the scope of this paper. We have described the standard from service-oriented solution for enterprise healthcare integration. Based on the above discussion PPEPR addresses the following integration requirements:

- Identifies the “semantic gap” between and within SOA, HL7 WS and SOA profiles.
- Applies ontologies (functional, behavioral) to resolve heterogeneity between service and process definitions.
- Design and provide ontological reference to public (choreography) and private (orchestration) behavioral descriptions.
- Provides a healthcare standard based flexible architecture that includes top-down and bottom-up development methodologies.
- Follows a semi-automatic integration approach, where ontologies (schema level) are constructed and mapped at design time to be mediated at runtime (instance level).
- Enables the “separation of concern”, between healthcare services and process.

3. Behavioral Semantics in sSOA for Healthcare

Healthcare is a complex domain, comprising vendors, standards, legacy systems, and information systems which differ inherently from one another. PPEPR provides a unique approach to interoperability. The core solution lies in enabling semantic interoperability between existing and new EPR systems. PPEPR is based on the design principles of a semantic SOA Reference Architecture and is built around semantic Web service technology. The PPEPR architecture considers three types of integrations between EPRs based on their Web service capabilities (or lack thereof).

EPR (non-Web service) ↔ EPR (non-Web service)
This type of interaction is focussed on existing EPRs, which are mostly HL7 v2.x based.

EPR (non-Web service) ↔ Web Service enabled EPR
This type of integration is the most complex (e.g. HL7 2.x ↔ HL7 v3), since EPRs (non-Web services) are required to communicate with the other EPRs (Web-services).

Web Service EPR (1) ↔ Web Service EPR (2) This type of integration in PPEPR architecture offers the best interoperability solution by achieving syntactic as well as semantic interoperability. Integration of this type is focus of this paper.

A detailed description of PPEPR and it’s architecture is available at [14]. The details of semantic Web service technologies [Web service execution environment (WSMX), Web service modeling language (WSML), Web service modeling toolkit (WSMT)] [4, 9, 11, 19], the conceptual framework Web service modeling ontology (WSMO), and BPEL for Semantic Web Services(BPEL4SWS) are outside the scope of this paper. PPEPR’s semantic Web service technologies are based on the WSMO framework [13]. For service’s external behavior, WSMO defines a choreography different to WS-CDL, i.e., WS-CDL defines a common global viewpoint of the observable behavior of collaborating services whereas in WSMO the choreography and orchestration is part of the interface definition of a service description. In PPEPR, the common global viewpoint is implicit as services are based on HL7 defined message exchange patterns (a.k.a. HL7 interaction or storyboard) and behavioral ontology is designed for semantic description of message exchange patterns.

The internal behavior of service is semantically described by functional ontology. HL7 categorises healthcare events (a.k.a HL7 trigger events) and the PPEPR functional ontology is based on this categorisation, where each HL7 trigger event is a Web service within PPEPR. A functional ontology is a semantic description of HL7 based healthcare events. Both HL7 versions differ syntactically in their structure of trigger events. Therefore, functional ontologies are created and mapped based on their similarity. To model and execute message exchange patterns, it is necessary to employ a process modelling and execution standard which is able to reference ontological elements and allow their mapping within the model. BPEL for Semantic Web Services (BPEL4SWS) [8, 10, 12] is a conservative set of language extensions to BPEL gives the possibility to reference ontological elements within a business process description. BPEL4SWS facilitates the orchestration of Semantic Web Services (SWS) at different levels of granularity.

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8http://www.oasis-open.org/apps/org/workgroup/semantic-ex/
10http://www.wsmx.org/
11http://www.wsmo.org/wsml/
12http://sourceforge.net/projects/wsmt
13http://www.wso2.org/
14http://www.ip-super.org/
15http://www.w3.org/TR/ws-cdl-10/
mantic Web Services using a process based approach and it is coupled with its ontological representation which is called sBPEL. In order to relate the semantics pertaining to one element in the BPEL4WS description an additional attribute `modelReference` (like SAWSDL [7]) identifies the corresponding ontological instance in the sBPEL process model.

The PPEPR mechanisms to discover and collaborate with services are end-point based (known at design time) as compared to WSMO goal-based mechanism. Even if the end-points of services are known, heterogeneous service and interface definitions are a major hurdle in automating the task of process mediation, service composition, orchestration, and choreography.

4. PPEPR Use Case

This section present a use case, see figure[1] which consists of six messages including request for patient’s lab test, lab test result, response, and confirmation messages.

The use case has three actors:

**EPR System, General Practitioner (GP)** This EPR is HL7 v3 compliant and it places a Lab test order fulfillment request to another independent EPR system [hospital laboratory].

**EPR System, Hospital Laboratory** This EPR is HL7 v2.5 and HL7 v2 Clinical Document Architecture (CDA) compliant. Hospital Laboratory receives the order for patient’s lab test results from HL7 v3, HL7 v2.x, and HL7 v2/v3 Clinical Document Architecture (CDA) compliant EPRs.

**EPR System, Galway Hospital** This EPR is HL7 v3 CDA (Clinical Document Architecture) compliant and receives lab test result from HL7 v (2.x, v2/v3 Clinical Document Architecture) compliant Hospital Laboratory.

Figure 3 show the choreography (message exchange pattern) of this use case and figure 4 show the process model of each actor.

Each actor has a specific ‘application role’ [e.g. Order Placer as General Practitioner (GP), Order Fulfiller as Hospital Laboratory, and Result Receiver as Galway Hospital and General Practitioner (GP)] and PPEPR acts as an integration platform. Based on this use case we describe in the section 5 how behavioral semantics are defined for both versions (HL7 v3 & v2) and how semantic Web service and process definitions are annotated by functional and behavioral ontologies.

16http://xml.coverpages.org/hl7CDA-Ann.html

5. Semantics for Service and Process Definitions

Figure 2 describes the PPEPR approach for developing semantically-enabled service (WSML) and process (sBPEL) definitions. Level 3 illustrates the semantic descriptions (functional ontologies) of EPR services, Level 2 illustrates the semantic definitions of service and process, and Level 3 is syntactic definition of service (WSDL[17]) and process(BPEL) [1]. To integrate a new EPR, a semantic service definition (Level 3 → Level 2, top-down) is created first whereas existing systems are integrated in bottom-up (Level 1 → Level 2) fashion. This involves a manual process of transforming WSDL/BPEL to WSML/s-BPEL. We are investigating means to incorporate the work in [17] to automate the WSDL ↔ WSML grounding task. Grounding and invocatio of services are performed at the semantically-enabled middleware (WSMX).

![Figure 2. Ontologising healthcare service (WSDL) & process definitions (BPEL)](image)

PPEPR’s functional and behavioral ontologies are designed to annotate service and process definitions. Figure 2 shows the choreography between the three actors of the PPEPR’s use case, where the Order placer (GP EPR) initiates the lab order fulfilment request. The request activates with a trigger event “Placer order activate” the mapping of a similar trigger event OML “021 is shown (in case GP EPR (order placer) is HL7v2 compliant). Order fulfiller (Lab) sends the confirmation receipt of an order followed by a trigger event (“filler promise activate(HL7v3)” or “ORU·022(HL7v2)”) that sends a promise message (which can also be rejected) to fulfill the order. The final two messages are the lab test results sent followed by the confirmation from the order receiver (Hospital EPR) and order placer (GP EPR).

17http://www.w3.org/TR/wsdl
Listings[1 to 5] show the snippets of the PPEPR namespaces, behavioral ontologies, mapping definition of functional ontologies and semantically enabled Web service definition.

Listing [1] describes namespace declarations of a message, functional, behavioral ontologies, grounding (WSML to WSDL), and General Practitioner (GP) EPR Web service.

Listing 1. Namespace declarations

```
namespace {
  dc "http://purl.org/dc/elements/1.1/",
  xsd "http://www.w3.org/2001/XMLSchema#",
  LabServiceGrounding "http://dev.ppepr.deri.ie/services/EPR_Lab.wsdl",
  GpServiceGrounding "http://dev.ppepr.deri.ie/services/EPR_GeneralPractitioner.wsdl",
  HLv3Fontology "http://dev.ppepr.deri.ie/HL7v3FunctionalOntology#",
  HLv2Fontology "http://dev.ppepr.deri.ie/HL7v2FunctionalOntology#",
  LabEPRbehavior "http://dev.ppepr.deri.ie/labEPRbehavioralOntology#",
  GpEPRbehavior "http://dev.ppepr.deri.ie/gpEPRbehavioralOntology#",
  b4s "http://ip-super.org/BPEL4SWS#",
  sa "http://www.w3.org/2002/ws/sawsdl/spec/sawsdl#",
  HL7v2 "http://www.hl7-v2.org#",
  HL7v3 "http://www.hl7-v3.org#" }
```

Listing 2 shows the ontological description of the trigger event (PlacerOrderActivate), see figure 3, of choreography defined above. Both functional ontologies are imported (line 2) in case mediation is required to represent equivalent HL7v2 trigger event (OML `021). PlacerOrderActivate is a “subConcept” (line 5) of an equivalent concept defined in the functional ontology. The behavioral ontology describes only those concepts of the functional ontology that are publicly visible and describes the state of choreography. For example, the ‘mode hasOut’ (line 9) means that it can only be changed by the GP EPR, ‘write access’ to outside environment is not permitted. A grounding mechanism (line 10) is provided that implements ‘read access’ for the outside environment. The ontology used to describe states in a WSMO choreography are extensions to the standard WSMO ontology. Attributes (e.g. ‘mode’) are defined as non functional properties.

Listing 2. Snippet of behavioral ontology for General Practitioner (GP)

```
ontology "http://dev.ppepr.deri.ie/gpEPRbehavioralOntology"
  importsOntology {
    "http://dev.ppepr.deri.ie/HL7v3FunctionalOntology#",
    "http://dev.ppepr.deri.ie/HL7v2FunctionalOntology#",
    "http://dev.ppepr.deri.ie/labEPRbehavioralOntology#"
  }
  concept PlacerOrderActivate subConceptOf
    HLv3Fontology#PlacerOrderActivate
    nonFunctionalProperties
      dc#description hasValue "sends order fulfillment request"
      mode hasValue hasOut
  grounding hasValue GpServiceGrounding#
  PlacerActivateLabOrder
  endNonFunctionalProperties
```

Listing 3 shows the behavioral ontology of Lab EPR (order fulfiller) and lines [6-13] semantically describes two
trigger events (e.g. FillerPromiseActivate, ResultEventComplete).

Listing 3. Snippet of behavioral ontology for Laboratory

Listing 4 shows the mapping definition between two semantically similar trigger events “ResultEventComplete” of HL7v3 and ORU®R01 of HL7v2, see figure. This mapping example is in the Abstract Mapping Language (AML) [15] syntax, which is formalism neutral, and grounded to WSML within WSMX. That means, WSMT stores the mappings definition in AML format and later(during mediation) PPEPR’s semantically enabled middleware (WSMX) grounds the AML to WSML. Lines [2-5] describe source (onto1) and target (onto2) ontologies, lines [6-7] is a single statement that defines mapping of “ResultEventComplete” to ORUR01.

Listing 4. Mapping definition (functional ontologies) of ResultEventComplete (HL7v3) & ORUR01 (HL7v2)

Listings shows the snippet of semantic Web service definition of General Practitioner(GP)’s EPR system. Considering the space constraint, the snippet only describes the structural arrangement of WSMO based semantically enabled service definition. Line 2 is a Web service URL of GP EPR, Lines [3-6] describe the Web service as non-functional property. Lines [7-9] import all required ontologies, and lines [10-13] describes the interface (GP_Interface) of the GP EPR. It describes how to interact with a service from the requester point of view (WSMO choreography) and how the service interacts with other services. Line 13 describes the “stateSignature” that is GP’s
behavioral ontology, as discussed above this ontology describes the states of WSMO choreography.

**Listing 5. WSML Web service definition for General Practitioner EPR**

As we discussed above, HL7 not only defines the message content, but also the business logic to achieve certain functionality in the health care domain. Figure 4 shows the process models of the order placer, fulfiller, and receiver to achieve the actual healthcare process. It is sufficient if three actors, the process placer, the process fulfiller, and the process receiver model and execute a process according to the message exchange patterns defined in HL7 and shown in figure 3.

**Figure 4. Business Process Models $ABC$ for Order Placer, Fulfiller, and Receiver in a HL7 Lab Test Order Request**

```
<sequence>
  <b4s:conversations>
    <b4s:conversation b4s:name="OrderPlacer"/>
    <b4s:conversation b4s:name="OrderFulfiller"/>
    <b4s:conversation b4s:name="OrderReciever"/>
  </b4s:conversations>
</sequence>
```

**Listing 6. Snippet of BPEL4SWS Order Placer(GP)**

Listings [6 to 8] shows how PPEPR’s functional ontologies are referenced by BPEL4SWS document, for example in listing 6, lines [1-4] is a new element `<b4s:conversation>` introduced by BPEL4SWS.

```
<sequence>
  <b4s:conversation name="OrderFulfillmentRequest" sa:modelReference="http://dev.ppepr.deri.ie/HL7v3FunctionalOntology#PlacerOrderActivate" partnerLink="OrderFulfiller" portType="spwsdl:OrderFulfillerPortType" operation="Fulfiller_ActivateLabOrder" variable="LabRequest" createInstance="yes"/>
  <extensionActivity>
    <b4s:invoke name="OrderFulfillmentRequestAck" modelReference="http://dev.ppepr.deri.ie/HL7v3FunctionalOntology#PlacerOrderActivateAck" b4s:inputVariable="RequestAck" b4s:outputVariable="OrderActivateFulfilmentRequest" b4s:conversation="FulfillmentRequest"/>
  </extensionActivity>
</sequence>
```
6. Lightweight PPEPR

The PPEPR ontologies and execution environment (WSMX) are based on a conceptual framework, the Web Service Modeling Ontology (WSMO). PPEPR uses the lightweight form of WSMO to meet healthcare enterprise integration needs. Below, we describe how PPEPR ontologies and the architecture are designed to be lightweight that they are interoperable with other semantic languages and semantic Web service framework (SWS).

- WSMO applies goal based approach for the task of discovering Web services. The Goal (requirements) of a services requester and the capability (what it can offer) of the provider are semantically described to achieve (total or partial) automation in the complete Web service discovery process [20, 21]. The PPEPR architecture is not goal based, end-points of EPR services are known to interacting services, thus service discovery is not the major focus of PPEPR.

- PPEPR uses the WSML language for describing domain-specific ontologies. PPEPR ontologies are lightweight in the sense that they use minimal common semantics (e.g. excluding ‘axioms’, ‘relations’, etc.) in PPEPR ontologies that can be easily converted to other semantic languages [e.g. RDF/RDFS\footnote{http://www.w3.org/RDF/}, OWL\footnote{http://www.w3.org/2007/OWL/wiki/OWL_World_Group}] without losing the semantics.

- PPEPR’s ontologies and architecture are designed to align with WSMO-Lite\footnote{http://www.w3.org/2002/ws/sawsdl/} and SAWSDL\footnote{http://www.w3.org/2007/OWL/wiki/OWL_World_Group} semantic Web service framework (SWS) for bottom-up healthcare service development and implementation. For example, service ontology defined by authors in [17, 18] is similar to the PPEPR functional ontology and it’s subset behavioral ontology. As SAWSDL is independent of any particular semantic technology PPEPR ontologies could be easily reused within the SAWSDL framework with minor or no modification.

- PPEPR’s multi-party process models (or orchestrations) is based on BPEL4SWS where processes can be exposed both as semantic Web services and conventional Web services i.e. A valid BPEL4SWS document is also a valid BPEL document.

7. Related Works

The two major streams of PPEPR related work are:
This is a 6th Framework EU integrated project aimed at setting up a set of regional semantics-based healthcare information infrastructure with the goal of reducing medical errors. In order to enable a seamless integration of eHealth services, Semantic Web Services technology is applied.

ARTEMIS [2, 16] This project is supported in the 6th Framework by the European Commission. ARTEMIS aimed at developing semantic Web Services based Interoperability framework for the healthcare domain. Artemis has a peer-to-peer architecture in order to facilitate the discovery and consumption of healthcare web services.

The major differences between eHealth projects described above and our approach are:

- The scope of PPEPR is enterprise wide, ARTEMIS and COCOON are Web-scale projects. The major focus of PPEPR is to ease the integration burden of service-oriented healthcare enterprises.
- ARTEMIS and COCOON employ primarily top-down approaches as far as semantics (ontology development) for service oriented architecture is concerned. PPEPR incorporates both the methodologies (top-down/bottom-up).
- PPEPR defines the clear "separation of concerns" for services and healthcare process model.
- PPEPR ontologies can be easily used in other SWS frameworks like SAWSDL.
- PPEPR ontologies are lightweight (uses only subset of WSML features). The major motivation behind this is to be interoperable with other standard semantic languages.
- PPEPR applies a new mechanism to describe the communication between two partners without a dependency on WSDL. As described in section 3 & 5 BPEL4SWS introduces a new element, \(<\texttt{b4s:conversation}\>\), which is not dependent on a \(<\texttt{partnerLinkType}\>\) and as such is not dependant on WSDL. This element enables the grouping of interaction activities and thus enables defining a complex message exchange between two partners. For example, Artemis introduced business process template “BP template” to model business process at design time. BP template is dependent on WSDL (e.g. \(<\texttt{partnerLinkType}\>\)) to describe a contract between two partners in terms of roles and corresponding WSDL portTypes. Also, for interaction activities “BP template” mainly relies on partnerLink and a WSDL operation. PPEPR clearly identifies the public and private behavior of interacting healthcare enterprises.

The PPEPR running demo[24] show the messages exchanged between actors of above defined use case.

8. Conclusion and Future Works

As we have discussed above, healthcare is a complex domain and any integration system, such as PPEPR, which connects healthcare enterprise applications must facilitate heterogeneous healthcare systems at all levels - data, services, processes, healthcare vendors, standards, legacy systems, and new information systems, all of which must interoperate to provide healthcare services.

In this paper, we describe the need of semantics in a service-oriented architecture (SOA) based healthcare integration system. We analyse the integration requirements of HL7 compliant healthcare enterprises at service and process levels. We present an approach to ontologies interaction behavior of service-oriented enterprise healthcare that enables interaction between healthcare enterprises in presence of heterogeneous service and process definitions. The paper also describes the latest results in the development of PPEPR, an integration system that connects enterprise healthcare applications at all levels (data, service, and process). PPEPR’s architectural and ontological designs are domain based. These designs and ontologies include both standard based ontologies (message, functional, and behavioral) and the definition of approaches used to develop them. PPEPR ontologies are lightweight to be interoperable with other semantic languages and semantic Web service (SWS) framework.

In our future work we plan to focus more on optimizing ontologies. This will have the result of reducing the size of ontologies and mapping definitions. We see this as PPEPR’s core strength compared to syntactic integration solutions. We plan to automate the grounding tasks (from XML/XMLSchema/WSDL to WSML and back) for both the HL7 versions (v2 & v3). In addition, we plan to incorporate uses cases with more complex HL7 message exchange patterns within PPEPR.

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