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ORIGINAL PAPER

Technical interoperability among EHR systems in Brazilian public health organizations

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Abstract

Allowing information exchange and cooperation among distributed and heterogeneous systems is important in the eHealth field. Development of interoperability standards and an approach based on Electronic Health Record (EHR) led to a significant evolution in this field. However, it has not yet been possible to find technical interoperability solutions among EHR systems for public health organizations in Brazil. In recent years, many researchers have faced the interoperability problem and have provided solutions, like interoperability models or architectures, based on different standards and technologies. This work presents a study of architectures proposed in the literature and selects one of them, using the AHP method, to support technical interoperability among EHR systems in Brazilian public health organizations. The architecture was selected according to the current scenario of eHealth in Brazil and in compliance with Brazilian legislation. A scenario of use of this architecture is also presented, where it is possible to perceive the feasibility of its application in the context of the Brazilian public health organizations. This application allows providing technical interoperability among isolated EHR systems that currently operate in health organizations and the sharing of EHR between them. It also shows that the architecture is generic enough to be adopted by diverse cities and flexible to changes, which allows adapting it to reduce costs, making its use possible in Brazil.

Key words: eHealth; EHR systems; electronic health record; interoperability architecture; technical interoperability

Resumo

Permitir a troca de informações e a cooperação entre sistemas distribuídos e heterogêneos é importante no campo da eSaúde. O desenvolvimento de padrões de interoperabilidade e uma abordagem baseada no Registro Eletrônico de Saúde (RES) levaram a uma evolução significativa neste campo. No entanto, ainda não foi possível encontrar soluções de interoperabilidade técnica entre os sistemas RES para organizações públicas de saúde no Brasil. Nos últimos anos, muitos pesquisadores enfrentaram o problema de interoperabilidade e forneceram soluções, como modelos de interoperabilidade ou arquiteturas, baseadas em diferentes padrões e tecnologias. Este trabalho apresenta um estudo das principais arquiteturas propostas na literatura e seleciona uma delas, usando o método AHP, para apoiar a interoperabilidade técnica entre sistemas RES em organizações públicas de saúde brasileiras. A arquitetura foi selecionada de acordo com o cenário atual de eSaúde no Brasil e em conformidade com a legislação brasileira. Um cenário de uso também é apresentado para demonstrar a viabilidade da aplicação dessa arquitetura no contexto das organizações públicas de saúde brasileiras. Essa aplicação permite fornecer interoperabilidade técnica entre sistemas RES isolados que atualmente operam em organizações de sáúde e o compartilhamento de RES entre eles. Também mostra que a arquitetura é genérica o suficiente para ser adotada por diversas cidades e flexível a mudanças, o que permite adaptá-la para reduzir custos, viabilizando seu uso no Brasil.

Palavras-Chave: Arquitetura de interoperabilidade; eSaúde; interoperabilidade técnica; registro eletrônico de saúde: sistemas RES

1 Introduction

Interoperability is essential in health systems since it enables their cooperation through data exchange in order to extract invaluable information to support treatment and monitoring of citizens' However, it is still a problem in Brazil. Computerization process in Brazilian health public organizations occurred in a disorderly way, and systems were developed without regarding Nowadays, isolated systems interoperability. operating concomitantly, including legacy systems, are easily found. Sharing and integration of health information are inhibited in this context, and data duplication is everywhere, such as the registration of a patient, leading to data redundancy and rework (Andrade et al.; 2013).

Technical interoperability, which addresses systems interconnection between interoperability standards, is a key factor in maintaining interoperable information systems. We highlight systems that deal with clinical documentation regarding a patient, i.e., deal with Electronic Health Record (EHR). EHR is a repository of information about the health of individuals, in an electronically processable form, being the EHR systems "systems for registration, retrieval, and manipulation of information from an EHR" (ISO;

In recent years, several technical interoperability solutions for EHR systems have been proposed, such as Hosseini et al. (2014) and Crichton et al. (2013). They are models or systems architectures, which make use of different technologies and paradigms. However, in this research, conducted from August 2015 to March 2017, it was not possible to find studies that indicate technical interoperability solutions among EHR systems specific to Brazilian public health organizations.

This work proposes an architecture to provide technical interoperability among EHR systems in Brazilian public health organizations based on an evaluation of different interoperability architectures proposed in the literature. It is also presented a use case scenario, where it is possible to perceive the viability of the architecture application in such organizations.

Section 2 discusses related works. Section 3 presents an overview of eHealth in Brazil. Section 4 discusses the health interoperability architectures researched. Sections 5 and 6 present, respectively, the results of the evaluation of these architectures and the architecture proposed. Section 7 presents conclusions and future work.

Related Work

In the literature review, no works were found proposing an architecture to support the interoperability between EHR systems for Brazilian public health organizations. Thus, in this section two works that present revisions of proposed solutions to support the interoperability between health information systems are described.

Siqueira et al. (2016) present a literature review elaborated to find out in what form and in what

contexts SOA (Service-Oriented Architecture) is applied to guarantee the interoperability of health information systems. The authors note that all the papers that present proposals make use of web services in order to make feasible the use of SOA. They also highlight the concern to guarantee the interoperability among legacy systems during the approaches analysis. The paper analyzes the interoperability of health information systems in general including, for example, intelligent home/environment systems and sensor network integration systems and not just systems that deal with EHR, the focus of this work. It is also not intended to select one approach for some specific purpose.

Hammami et al. (2014) highlight the works that they consider most relevant to the interoperability of health information systems and present a comparative study of the three most used technologies: ontology, SOA and cloud computing. The authors' proposal is to merge these technologies to develop an interoperable health information system. The focus is semantic and not technical interoperability, and the comparison of the technologies used by the selected approaches. In addition, the authors analyze papers that deal with the interoperability of health information systems in general, as well as the work of Siqueira et al. (2016). Therefore, the aim of the authors is not to propose an interoperability architecture but a system.

The results presented in these two works differ in scope and objective of the results presented in this work. While the two related works have a wider scope, with the revision including other sorts of health information systems, this work has a specific focus on EHR systems, with the objective of selecting a technical interoperability architecture targeted to these systems. None of the related works aims to propose a technical interoperability architecture, in particular for the Brazilian eHealth scenario, as this work proposes.

3 eHealth in Brazil

Brazilian health information systems have very heterogeneous technological and operational There is no standardization of characteristics. programming languages or databases. The lack of interoperability and fragmentation of information are also some of the shortcomings of these systems developed and maintained by the Ministry of Health. The Brazilian government has made some initiatives to promote support for technical interoperability, such as the e-PING architecture (Brasil. Ministério do Planejamento, Orçamento e Gestão; 2016), the ordinance no. 2,073, of August 31, 2011 (Brasil. Ministério da Saúde; 2011), from the Ministry of Health, and specifications for integration with the CNS (the national health card).

e-PING defines a set of premises, policies and technical specifications towards achieving interoperability in e-government services (Brasil. Ministério do Planejamento, Orçamento e Gestão; 2016, 2015). Ministerial ordinance no. regulates the use of health information standards and interoperability among information systems

at all levels of government, as well as private and supplementary health systems. HL7 standard (International; n.d.) was selected as the official data/message transfer standard, aiming to integrate the results and requests for medical exams. SOAP (Simple Object Access Protocol) web services will be used for interoperability support. Legacy systems can communicate with other systems by encapsulating their answers in XML, using the XML Schema of the homologated standard (Brasil. Ministério da Saúde; 2011). CNS is a univocal identification (ID) of users of SUS (the national health system). It allows monitoring of care provided by the health system, wherever they occur, preserving privacy and autonomy of citizens.

SUS Primary Care Strategy is supported by two systems: SISAB (Health Information System for Primary Care); and e-SUS AB (e-SUS Primary Care System). SISAB is the national health information system and e-SUS AB is composed of software systems that support the work process in UBS (primary health care facilities) (Brasil. Ministério da Saúde; 2016b). Some documents were created to meet particular characteristics of each block of information handled by those systems. We highlight RAS (simplified care record) and RAC (comprehensive care record). RAS is generated from individualized and identified health events and corresponds to a basic set of information transmitted to SISAB. RAC, in addition to RAS information, adds a more structured set of information, which seeks to make the system compatible for future sharing of EHR data (Brasil. Ministério da Saúde; 2016b). In the current version of e-SUS AB system, only RAS is available (Brasil. Ministério da Saúde; 2016a).

Interoperability architectures in health area

Different solutions to solve technical interoperability problem of EHR systems have been proposed. Tab. 1 summarizes sixteen researched works and their technologies.

Table 1: Works about technical interoperability of EHR systems

	SOA	Cloud	Agents	ESB	HL7
AlJarullah e El-Masri (2013)	X				X
Andrade et al. (2013)				X	X
Barbarito et al. (2012, 2015)	X				X
Brzezinski et al. (2011)	X				X
Crichton et al. (2013, 2015)	X			X	
Fragidis et al. (2016)	X				
Gong e Chen (2010)	X				X
Herand et al. (2013)	X				X
Hosseini et al. (2014)	X				X
Lupse et al. (2012)	X	X			
Mannaro et al. (2013)	X	X		X	
Placido et al. (2012)	X				
Rheinheimer et al. (2004)			X		
Ryan e Eklund (2010)	X			X	X
Sernani et al. (2013)			X		
Zhang et al. (2009)	X			X	

SOA is the approach most frequently adopted. Integration between SOA and other techniques such as agents and cloud computing was also observed. According to Sernani et al. (2013), integration between multi-agent and SOA architectures is as possible as desirable. The direction of the integration researches is defining the relationship between services and agents, where services provide computational resources, while agents provide a coordination framework (Giacomo et al.; 2011).

SOA-based applications can be deployed and hosted in a cloud. Cloud architecture is probably a good solution to efficiently host a web service because there is no limit to data size, processing power, and the number of services. However, some problems can occur in health information systems, since data is stored in the provider's cloud infrastructure, which is illegal in many countries that require data privacy and patient safety. Moreover, provider failure results in unavailability of patient data. Accordingly, there are still few solutions of health information systems based on cloud computing (Hammami et al.; 2014).

Concerning the use of data/message transfer standards, HL7 v3 is used in Hosseini et al. (2014), Herand et al. (2013), Andrade et al. (2013) and Gong and Chen (2010). Barbarito et al. (2012, 2015) used HL7 v2.5 for compatibility issues with legacy systems. AlJarullah and El-Masri (2013), Lupse et al. (2012), Brzezinski et al. (2011), and Sernani et al. (2013) use structured XML messages according to HL7 CDA. Although Mannaro et al. (2013) and Plácido et al. (2012) mention HL7, do not claim to use it. Fragidis et al. (2016) make use of FHIR standard (HL7 Community; n.d.). Crichton et al. (2013) are standard independent, i.e., the adopted standard is encapsulated in normalization and de-normalization routines, facilitating upgrade or standard substitution.

Security issues are addressed in several ways. Security in message transfer is adopted somehow by Crichton et al. (2013) and Brzezinski et al. (2011). Errors handling is observed in Barbarito et al. (2012, 2015), Crichton et al. (2013), and Ryan and Eklund (2008, 2010). AlJarullah and El-Masri (2013) and Fragidis et al. (2016) propose data transfer in a secure and private WAN (Wide Area Network); Lupse et al. (2012) suggests a private cloud infrastructure to each health unit; and Hosseini et al. (2014) use security features provided by Microsoft WCF (Microsoft; n.d.).

Regarding implementation costs, some of the proposals generate high infrastructure costs, such as a WAN and a private cloud. Other proposals suggest acquisition of private software licenses, such as Barbarito et al. (2012, 2015) that uses the ESB Java Caps (currently Oracle SOA Suite), Hosseini et al. (2014) that makes use of Microsoft WCF (although there is an open-source WCF version with limited resources) and Herand et al. (2013) that suggests the use of SOA governance technology from Software AG. These architectures would require a large investment, which could be a problem for most Brazilian public health organizations. However, these solutions can be replaced by cheaper ones. For example, a WAN can be replaced by a VPN taking due care with security, just as a private software can be replaced by a similar open source. The following subsections present details of each work.

4.1 Architecture of AlJarullah and El-Masri

The AlJarullah and El-Masri (2013) approach proposes that summarized EHR be kept centrally in a national health system with reference links for its full versions in their original locations. In other words, the semicentralized system stores a summarized copy of each EHR of each health unit in the central system. The central system, called the National Health Center (NHC), also provides access to full versions of these EHR taken from distributed health care providers, the Health Care Centers (HCs).

HCs have heterogeneous information systems and to provide interoperability between them, a small system called Health Information System Broker (HISB) must be built in each HC to control the communication of patient data from the local database in the HC to the NHC. The proposed architecture is based on three-tier design. The layers set includes the following: (i) Data Layer - which manages the data stored in the NHC database; (ii) Business Layer - which includes the main processing modules; and (iii) Presentation Layer - which accepts input, forwards queries to requested processes or modules in the business layer, in particular, the NHC modules, and displays the results.

4.2 HL7Middleware Architecture by Andrade et al. (2013)

Andrade et al. (2013) propose an architecture called HL7Middleware. This architecture consists of two main components: an HL7Server, which communicates with a central data repository and different health systems and a set of HL7Wrappers, which implement interfaces for certain legacy systems. The HL7Server is responsible for receiving and interpreting HL7 messages, performing database operations, and sending responses to the client system as HL7 messages. Any system that implements HL7 v.3.0 messages can act as a client.

The architecture HL7Middleware consists of: (i) a server that operates as an HL7 message bus; (ii) a set of message templates and stored procedures that represent database access functions associated with each message category; (iii) a mapping of messages, fields, and stored procedures to a database; (iv) a database or set of databases and (v) client systems of different types.

4.3 Architecture of Barbarito et al. (2012, 2015)

Barbarito et al. (2012, 2015) describe the implementation process of the Regional Social and Healthcare Information System in the region of Lombardy, Italy. The system implements a three-tier architecture. At the highest level, both the administrative data and the clinical data of each citizen are managed. A connective infrastructure, the Extranet, provides communication between different actors and represents the intermediate level between the central domain (first level) and local health care providers and organizations (third level).

All processes and functions for system integration

are based on the middleware Java Composite Application Platform Suite (JCAPS). JCAPS, which is based on SOA, provides the integration of different applications through HL7 messaging, the creation of integration adapters for use in applications without the native adoption of HL7, and the management of server-side services for integration. The version of the HL7 standard adopted was the most frequently used in existing systems — HL7 version 2.5. The standard chosen for the structuring of documents was the HL7-CDA 2.

4.4 HIP Platform of Brzezinski et al. (2011)

The Brzezinski et al. (2011) solution, called the HIP (Healthcare Integration Platform), is based on the SOA paradigm using web services RESTful. Their responsibilities are divided between five web services: Source, Index, Registry, Authorization, and Mediator.

The web service Source performs various tasks on the platform: sending patient's personal data, making medical documentation available and sending information about it. An instance of such service is attached to each health unit and gets data using a wrapper, which converts this data into documents in HL7 CDA format. Source is able to submit information about new patients to a suitable index within the platform in order to identify them among different health care providers. Source can still act as an independent document repository or a mediator in retrieving data directly from the system within a healthcare unit. For each new document, Source is responsible for generating metadata and sending them to the Registry service. Index is a service whose sole purpose is to identify patients by assigning them unique identifiers.

Index provides consistency of such identification by sharing the identifiers between all services within the platform. Registry is an indexing service that organizes document metadata. In addition, Registry has the information about the current addresses of the Source services and thus acts for the platform as a catalog of units. Authorization is a simple web service with tools to manage the data needed to guarantee access to the platform. Mediator is an entry point for data shared across the platform and defines an API for applications that connect to the platform. It uses all other services to efficiently search and view medical data.

4.5 OpenHIM Architecture by Crichton et al.

Crichton et al. (2013) describe the design of an architecture that aims to provide interoperability between health information systems in Rwanda. In the context of Rwanda's national health information system, the systems OpenMRS (an Electronic Medical Record (EMR) system) and RapidSMS (a datacollection SMS-based tool), will interoperate with a set of key infrastructure services in order to share information. To provide interoperability, a new component has been added — the Health Information Mediator (HIM).

HIM is an ESB developed with the opensource Mule platform and incorporates a RESTful

web services approach. It contains three main components: (i) Interface component that exposes an API through web services that allows systems or applications to make service requests; (ii) Persistence component which receives authorized service requests from the interface component and initiates and monitors a transaction that is required to fulfill the request until completion; and (iii) Mediation Component that performs transactions and contains the logic necessary to normalize, orchestrate, and de-normalize transactions.

Normalization transforms the request message into a normalized state, for example, a message HL7 v3. The orchestration executes the received transaction and any consequential action required for this transaction. De-normalization is similar to the normalization process, but the operations occur in reverse order, transforming the message so that it is understandable to the service provider.

architecture is independent data/message transfer standard, that is, any data can be exchanged as long as the normalization and de-normalization transformations are defined because they allow the data to be transformed to a format that the mediation component is able to understand and orchestrate. HIM is currently an open-source project called OpenHIM (Open Health Information Mediator).

4.6 Architecture of Fragidis et al. (2016)

Fragidis et al. (2016) present an approach very similar to that of AlJarullah and El-Masri (2013). The architecture, classified as semi-distributed, has as main entities: the Ministry of Health (MH), the Health Districts (HD), the Medical Assistance Organizations (HCPO), Private Doctors (PD), Diagnostic Centers (DCs), Private Laboratories (PL) and the Citizen. MH hosts the NHAS (National Health Authentication Service), which provides access rights to all entities. For each entity, a unique identifier has been assigned. Another service that is located on MH is the Citizens Health Record Locator Service (CHRLS). This service provides location information for specific HDs that maintains the data for the requested Citizen Health Record (CHR).

The HD hosts the Basic Citizen Health Record Provider (BCHRP) service that provides the basic citizen health record data. In addition, on each HD there is a Citizens Health Record Locator (CHRL), which provides location information for CHR data within the boundaries of each district. To allow each HCPO to communicate with the nationwide EHR system, a Health Information Middleware Interface (HIMI) must be installed in the organization. The primary operation of HIMI is to transform HCPO health data and provide health information using the Clinical Information Modeling Initiative (CIMI) for other health service providers.

The exchange of health data among health care providers is carried out according to the Fast Healthcare Interoperability Resources (FHIR) standard set up by HL7. These HIMIs are essential for achieving interoperability between heterogeneous health information systems, which are eventually installed in each HCPO, DC, PD and PL. Each HIMI should be designed specifically for each health care

provider's database schema.

4.7 HIISP Platform of Gong and Chen (2010)

Gong and Chen (2010) propose a SOA-based integration platform called HIISP (Healthcare Information Integration and Shared Platform). HIISP has four key components: (i) a normalized data repository based on the HL7 standards; (ii) a set of data management services that ensures that data in the repository is consistently represented so that other health organizations can maintain a unique view of patients and health service providers; (iii) a messaging platform that allows different types of information systems to communicate; and (iv) a J2EE-compatible development platform that helps independent software vendors build complementary health applications.

HIISP messaging services are based on the HL7 v3 standard and are critical to the integration of heterogeneous third-party data systems. The inbound message processor, in conjunction with the HIISP API, has support for consistent storage of data from legacy systems. The outbound message processor allows HIISP to communicate with external systems. Messaging services use terminology services that provide tools for crossstandard conversions.

4.8 Model of Herand et al. (2013)

Herand et al. (2013) present a model that combines the HIISP of Gong and Chen (2010) with the SSF (HSSP Service Specification Framework) standards developed by the HSSP¹ (Healthcare Services Specification Project) framework, under the leadership of HL7 and the Object Management Group.

The authors suggest the use of SMART (Service-Oriented Migration and Reuse Technique) strategies of Smith (2007) and Zhang et al. (2008)'s black box for the migration of legacy systems to SOA. The SMART strategy is a technique to initialize the analysis of legacy system components to assess their potential for reuse as services. The black box strategy of Zhang et al. (2008) proposes to export the functionalities of legacy systems towards web services using a wrapping methodology suitable to GUI-based legacy systems. For service orchestration, the authors recommend the use of the Software AG's SOA governance technology.

4.9 Architecture of Hosseini et al. (2014)

Hosseini et al. (2014) present a system architecture based on SOA and HL7 v3 to support clinical decision regarding immunization in Iran. Two immunization information systems were developed and a solution was proposed to achieve interoperability between them. Two web services were implemented following HSSP recommendations. The first, called EIS (Entity Identification Service), defines a set of service interfaces to identify various types of entities (e.g.,

¹https://hssp.wikispaces.com/

patients, providers) within heterogeneous systems. The second, called RLUS (Retrieve, Location, and Updating Service), allows health data to be located, accessed, and updated. Web services were built based on Microsoft WCF technology in C# language. The protocol used to exchange HL7 v3.0 messages based on XML is SOAP and the location of the services and their operations are described through the WSDL (Web Services Description Language).

4.10 Architecture of Lupse et al. (2012)

Lupse et al. (2012) propose an architecture based on cloud computing. Among cloud development models, authors point to private clouds as the most appropriate for medical applications, for data security and privacy reasons. Private clouds are owned by a single organization and are used only in this organization.

The architecture was deployed in two departments of a hospital: Pediatrics and Obstetrics-Gynecology. Applications and data storage can be found within each department's private data center (one in the Department of Pediatrics and one in the Department of Obstetrics- Gynecology). When it is necessary to transfer patient data from one department to another, both with different health information systems, these are transmitted in real time to the appropriate location using an XML messaging solution based on the HL7 CDA standard. The applications were developed for each department separately (Pediatrics and Obstetrics-Gynecology) and also the support for communication in a local network. In sequence, the upload of applications in the cloud and their interconnection were carried out.

4.11 Architecture of Mannaro et al. (2013)

Mannaro et al. (2013) propose a model that presents features of the ESB infrastructure and cloud computing. This research work is part of an industrial project in conjunction with a private company to develop a virtual organization². This virtual organization should consult laboratories, hospitals and EHR repositories to obtain the complete

The architecture employs a middleware subsystem that acts as a communication interface between organizations, ensuring interoperability between heterogeneous data and services, as well as a reliable and secure EHR. Integration between architectural elements is implemented as a centralized strategy where middleware is the actor that links the services, allowing them to communicate correctly, helping them to understand the messages and eventually providing a secure communication channel. The architecture benefits from the ESB software infrastructure in terms of middleware functionality, and cloud services in terms of scalability.

4.12 Architecture of Plácido et al. (2012)

Plácido et al. (2012) propose an architecture that aims to respond to the needs of interoperability between heterogeneous health information systems and the need for the ubiquity of medical information. To ensure interoperability between different systems, the architecture is based on web services and specifications such as WSDL and SOAP. Web services are also used for communication with mobile devices with the Android platform making use of ubiquitous computing. The Hospital, Primary Care and Medical Emergency subsystems represent the hospitals, health centers and medical emergency respectively.

The GLOBAL subsystem is where the patient can obtain their medical and personal information. The subsystems of the different institutions replicate the information in their databases with the GLOBAL subsystem database on a daily basis. GLOBAL subsystem consists of a multi-tiered application, with the creation of an access interface for mobile devices that use web services the WSM. To promote interoperability between subsystems Hospital, Primary Care and Medical Emergency, another component was created — the BROKER. BROKER encapsulates the interface and the operations that one subsystem uses to obtain information from another subsystem.

4.13 WSAgent architecture of Rheinheimer et al. (2004)

Rheinheimer et al. (2004) propose the use of web services in order to link agents to EHR systems functionalities so that they communicate with other agents linked to other EHR systems. Interactions happen through XML-based messages exchanged through Internet-based protocols. The architecture called WSAgent consists of three layers: the first one uses web services in the role of software agents to perform the communication between systems; the second represents data using ontologies and contains the business rules that are used to process the data exchanged among systems; the third one consists of a Framelet (a small Framework) that is responsible for the persistence of data, storing the information received in several databases.

The operation of software agents is guided by information defined with ontologies. In this way, an agent working in a particular process can be configured to work in another process just by connecting a new ontology layer, which defines structure and rules for handling specific data. The persistence layer used by all agents is the same. Framelet makes it possible to customize the type of database system desired. The overall solution to be used by an organization consists of several instances of the architecture described: a number of custom software agents with specific ontologies and business rules tailored to a specific database system and linked to system features that will activate those agents when required.

²A virtual organization refers to the sharing of resources of different organizations to enable the collaboration of a group of people or institutions (Tanenbaum and Steen; 2007)

4.14 HSB architecture of Ryan and Eklund (2008, 2010)

Ryan and Eklund (2008, 2010) propose an interoperability architecture called Health Service Bus (HSB). HSB is essentially an ESB using health standards within its message formats. An HSB implementation prototype was created using Mule ESB, making use of various services connected to the

The prototype has the following components: (i) Translation Service that allows direct translation between HL7 v2 and HL7 v3, and HL7 v3 and OpenEHR, where the translation between HL7 v2 and HL7 v3 enables legacy systems to communicate in the HSB and the translation between HL7 v3 and OpenEHR aims to translate messages from HSB into OpenEHR for storage in the database; (ii) E-mail delivery service, which automatically send emails to a designated address when errors occur in the HSB; (iii) Content-Based Router, responsible for examining the content of a message and routing it based on the information contained in the message; (iv) Patient Records in HSB, where continuous patient records in the OpenEHR format are stored in an XML database connected to the HSB. Technical interoperability is achieved by the core structure of the HSB, specifically the core of the message bus.

4.15 Architecture of Sernani et al. (2013)

A multi-agent architecture is proposed in Sernani et al. (2013). The architecture is represented by three layers of abstraction, named Local Platform, District Platform, and Client Platform. There is a Local Platform for each health facility in the territory (e.g. a hospital); Facilities belong to administrative districts, which constitute the second layer of architecture; The client layer is represented by any software agent that needs to access the infrastructure to retrieve/insert data.

The Local Platform has the role of providing interface with any information system present in the structure. The agents of the Local Platform are: (i) LocalDBWrapper - provide an interface with the databases of a local healthcare institution; (ii) DocumentHandler - able to access the contents of a clinical document produced at the facility, such as a laboratory examination; (iii) Service Agents manage different healthcare services (e.g. radiology, analysis lab, etc.).

The main task of the District Platform is to encapsulate all the local platforms that belong The agents of the District Platform are: (i) DistrictDBWrapper - manage data in the district databases; (ii) DocumentHandler - manage documents that are the administrative responsibility of a district; (iii) Gateway - captures client requests and queries local and district wrappers to retrieve data about any citizen health record; (iv) Init registers the same platform Gateway for all active DF_Inter-district agents of the territory's remote district platforms during the initial phase of the district platform; (v) DF_Inter-district - is the Directory Facilitator (DF) where all remote gateways are registered; (vi) DF_Intra-district - this DF

contains all records of LocalDBWrapper agents from local platforms belonging to the same district; and (vii) LoginServer – establishes a secure connection with the client that wants to access the infrastructure to retrieve data in a specific district.

4.16 Architecture of Zhang et al. (2009)

Zhang et al. (2009) present the architecture of the Interoperable Medical Information System. This system is based on SOA and the health facilities are service providers who create web services and publish them through a UDDI (Universal Description, Discovery and Integration) registry. Hospitals, patients, and clinics are service requesters who use UDDI to find the services they need and link them to service providers. The system server provides the patient identifier, visitor authentication, and storage of hospital's services information. An interface server is placed in each hospital and acts as an intermediary between the hospital systems and the system server. Interface servers are responsible for converting the data to XML format.

The architecture is divided into layers that include portal, connection, business process, services, security, and service management. At the portal layer different portal interfaces are offered to the various service requesters. The connection layer provides several data access interfaces. It supports several transport protocols, as well as many databases. The business process layer organizes the services according to the needs of the service requesters. The service layer is a set of service providers, including authentication, data, and log services. The security layer provides security management and quality assurance of system services.

The service management layer is the ESB layer, and its main responsibilities are: (i) version management of all services; (ii) register for new services; (iii) repository of all web services and all versions available for each service; and (iv) management of the rules and policies of the web services available. The architecture adopts Microsoft .NET as a development platform and uses SOAP, WSDL and UDDI technologies in web services.

5 Architectures Evaluation and Analysis

Decision-making method AHP (Analytic Hierarchy Process) was used for choosing which architectures could be adopted by Brazilian public health organizations. AHP is a theory of measurement through comparisons in pairs and relies on expert judgments to derive priority scales (Saaty; 2008). AHP method applied to ternary comparisons (Takahashi; 1990), was also used in the evaluations based on whether an alternative "meets" defined criteria, "does not meet", or "cannot be reported", the latter in case of uncertainty or indeterminacy (Takahashi; 1990).

5.1 Alternatives

Firstly, eliminatory requirements the for architectures evaluation were defined based on technical requirements collected in

documentation of e-PING, CNS and Ministerial ordinance n.º 2.073. They are the use of web services (SOA) and the HL7 conformance. Even not meeting this latter requirement, remain in the selection the Crichton et al. (2013) architecture which is independent of data/message transfer standard and the Fragidis et al. (2016) architecture for using the new FHIR standard, since its study could bring contributions to this research, such as requirements to support this standard in the future. Thus, seven architectures were evaluated: Barbarito et al. (2012, 2015), AlJarullah and El-Masri (2013), Fragidis et al. (2016), Crichton et al. (2013), Ryan and Eklund (2008, 2010) Gong and Chen (2010) and Brzezinski et al. (2011).

5.2 Evaluation Criteria

Some quality attributes generally considered in the SOA context (O'Brien et al.; 2007), such as security, maintainability, location transparency and scalability, were used as evaluation criteria, in addition to the criterion of legislation compliance. Weights were defined according to Brazilian public health organizations scenario and current legislation. Fig. 1 shows the decision hierarchy with these criteria according to AHP.

Legislation compliance checks architectures use SOAP, XML, and HL7 standards (HL7 v2.x, HL7 v3 or HL7 CDA), according to Brazilian ministerial ordinance no. 2,073.

Interoperability criterion regards platforms, languages, and protocols adopted by the architecture (O'Brien et al.; 2007). It is divided into legacy systems and standard update support. The first one evaluates if the architecture provides some mechanism that allows interoperability with systems that use data/message transfer standards different from the one adopted by the architecture, or if it packages the legacy systems as services. The second evaluates if the architecture presents some type of support for updating the data/message transfer standard.

Security is related to web service security levels and error handling. It is divided in message level, which evaluates if the architecture uses encrypted messages in the network; transport level that evaluates whether the architecture uses a secure protocol for data transmission (e.g. HTTPS); and error handling, which evaluates if the architecture handles errors.

Maintainability criterion evaluates

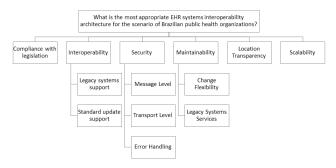


Figure 1: Decision Hierarchy

architecture support changes in a system and it is divided into two subcriteria: flexibility to change, which evaluates if services in the architecture have low coupling and high cohesion; and legacy systems services, that evaluates if the architecture provides legacy systems functionalities as services.

Location transparency evaluates if architectures provide some service registry, such as UDDI or ebXML, or present a single interface so that client systems can access components of the architecture, or use ESB, which can be used as an intermediary layer between client and service (Keen; 2004; Pan and Pohl; 2010).

For scalability criterion, classification of architectures regarding the EHR repository was used. It was noticed distributed architectures have low scalability, since high traffic in the network can affect the performance of the system when scaled; meanwhile, centralized architecture presents high scalability, because it generates less traffic in the network; semi-distributed architecture, therefore, has moderate scalability, since it is a blend of both previous approaches.

Comparison between criteria, regarding Brazilian public health organizations, can be expressed as a matrix, which is converted into a criteria ranking by calculating it's normalized eigenvector (Saaty; 2008). Tab. 2 shows this comparison matrix and the ranking (eigenvector) of the criteria regarding our goal.

Table 2: Pairwise comparison of criteria regarding

our goar							
	CO	IN	SE	MA	LO	SC	Eigenvector
CO	1	2	3	4	4	5	0,3689
IN	1/2	1	2	3	4	4	0,2481
SE	1/3	1/2	1	2	3	4	0,1638
MA	1/4	1/3	1/2	1	2	3	0,1034
LO	1/4	1/4	1/3	1/2	1	2	0,0685
SC	1/5	1/4	1/4	1/3	1/2	1	0,0474

Where CO = Compliance with Legislation, Interoperability, SE = Security, MA = Maintainability, LO = Location Transparency and SC = Scalability.

5.3 Results

Fragidis et al. (2016) architecture does not meet the legislation compliance criterion since it does not use the HL7 standard, but the most recent FHIR. Instead of SOAP, Crichton et al. (2013) and Brzezinski et al. (2011) use the REST architecture, hence do not meet this criterion. AlJarullah and El-Masri (2013) and Ryan and Eklund (2008, 2010) do not inform the standard adopted. Concerning interoperability subcriteria, all architectures support legacy systems. Support for updating standards could only be confirmed in Crichton et al. (2013) work. None of the others authors address this issue.

About security subcriteria, regarding the analysis of message level, no author claims whether encrypted messages travel on the network, except Crichton et al. (2013) that remarks this question is still pending in their architecture. Crichton et al. (2013) and

Brzezinski et al. (2011) use the HTTPS protocol and therefore meet transport level subcriteria. The other authors do not mention the protocol used. Error handling is cited only in Barbarito et al. (2012, 2015), Crichton et al. (2013), and Ryan and Eklund (2008,

According to flexibility to changes subcriterion, related to maintainability, architectures of Barbarito et al. (2012, 2015) and Brzezinski et al. (2011) are not highly cohesive, as their services have several responsibilities. In the architecture of AlJarullah and El-Masri (2013) components that provide interoperability among systems are tied to business processes and specificities of use cases, requiring changes in the legacy systems to adapt to the architecture; therefore, it has high coupling and is difficult to maintain since it propagates modification. The work of Fragidis et al. (2016), which has a very similar approach to the work of AlJarullah and El-Masri (2013), corrects this problem and hence satisfies this subcriterion. In Crichton et al. (2013) a modification in a component (transaction) propagates changes to other components (OpenHIM reference application and its mediators), so this architecture does not meet low coupling requirement. Ryan and Eklund (2008, 2010) architecture presents independent services with unique responsibility and thus met this subcriterion. Although services present in the Gong and Chen (2010) architecture have unique and focused responsibilities, indicating high cohesion, there is not enough information to tell whether the architecture has low coupling.

Regarding legacy systems services subcriterion, the architectures of Crichton et al. (2013) and Ryan and Eklund (2008, 2010) support wrapping of legacy systems as services, since this is a feature of ESB Mule [34]. Barbarito et al. (2012, 2015) architecture also presents this support, since it uses ESB JCAPS (Oracle; n.d.), which provides this functionality. Brzezinski et al. (2011) claim to offer this support.

Architectures that meet location transparency criterion, authors cite issues such as single interface and ESB architecture. Fragidis et al. (2016) and Gong and Chen (2010) do not use these approaches, nor mention service registration.

In order to analyze the scalability criterion, classification of the architectures regarding EHR repository was used. Crichton et al. (2013), Gong and Chen (2010) and Ryan and Eklund (2008, 2010) are classified as Centralized, AlJarullah and El-Masri (2013) and Fragidis et al. (2016) as Semidistributed and those of Barbarito et al. (2012, 2015) and Brzezinski et al. (2011) as Distributed.

Ranking of alternatives for each criterion is determined by the eigenvectors of the pairwise comparisons matrices regarding each criterion. Tab. 3 shows these rankings. The final ranking is calculated multiplying the matrix formed by the eigenvectors of the ranking of alternatives (Tab. 3) by the matrix formed by the eigenvectors of the matrix of criteria regarding our goal (Tab. 2). Tab. 4 shows the final ranking, with the selected architecture highlighted in bold.

Proposed architecture

The comparative evaluation performed through the AHP method indicated the architecture of the Regional Health Information System of Lombardy, Italy, Barbarito et al. (2012, 2015), as the solution to support the technical interoperability among EHR systems of Brazilian public health organizations. In this architecture, technical interoperability of EHR systems is separated into two layers: health organization level and regional level. The architecture provides three software components to support regional interoperability: Client Web Service Broker (CWSB), Batch Web Service Broker (BWSB) and Application Gateway (AG).

CWSB acts as a bridge between the service provider and requester and is installed on all PCs of healthcare professionals in a region. It uses a catalog to identify how to route the web service call to the provider that offers the service. In some cases, it can also perform some value-added functions, for example, according to the catalog, a service may require the real-time generation of a document to be digitally signed by the professional who is invoking the service. BWSB interfaces between the Extranet and the health organization's Intranet. It is used when messages are sent by servers from healthcare organizations rather than PCs used by healthcare professionals.

Finally, AG interfaces receive requests for invoking web services from clients on the Extranet and forwards them to servers on the organization's Intranet which offer the service. It also performs authorization controls according to web services catalog using the VPC (Verification of Privacy Criteria) service from central domain. This web service controls access to patient EHR (Barbarito et al.; 2015). In some cases, AG may perform some value-added functions, e.g., according to the catalog, a specific service may require the transmission of a digitally signed document. In this case, the AG will check the signature before forwarding the request through the Intranet.

To provide interoperability at the health organization level, an ESB JCAPS architecture based on SOA is used. It provides integration of different applications through HL7 messaging, creation of integration adapters for use in not HL7 compliant applications, and management of server-side services for integration. There are two types of applications to integrate: applications with and without a native HL7 interface. In both cases, technological adapters are used for integrating: in the first case, the adapter does not intervene in the message content; in the second case, the adapter creates HL7 messages from the non-HL7 native application. Fig. 2 shows an example of the architecture of interoperability at the level of health organization applied in a hospital. We can see that the interoperability of EHR systems is through middleware (ESB JCAPS), which manages all HL7 messages exchanged between local systems and repositories. The CWSB, BWSB and AG components interface the Hospital intranet and the Extranet, allowing the connection to the central domain and other health units (Barbarito et al.; 2012).

In Brazilian public health organizations, at the municipal level, a necessary change in the

Table 3: The score achieved on each of the criteria						
	Compliance with legislation	Interoperability	Security	Maintainability	Location Transparency	Scalability
Barbarito et al. (2012, 2015)	0,304	0,135	0,148	0,131	0,176	0,041
AlJarullah and El-Masri (2013)	0,110	0,135	0,136	0,064	0,176	0,096
Fragidis et al. (2016)	0,058	0,135	0,136	0,192	0,059	0,096
Crichton et al. (2013, 2015)	0,058	0,190	0,126	0,131	0,176	0,242
Ryan and Eklund [2008, 2010]	0,110	0,135	0,148	0,259	0,176	0,242
Gong, YG. and Chen, X. (2010)	0,304	0,135	0,136	0,092	0,059	0,242
Brzeziński et al. (2011)	0,058	0,135	0,170	0,131	0,176	0,041

Table 3: The score achieved on each of the criteria

Table 4: Final Ranking

	Final Ranking
Barbarito et al. (2012, 2015)	0,197
AlJarullah and El-Masri (2013)	0,119
Fragidis et al. (2016)	0,105
Crichton et al. (2013, 2015)	0,126
Ryan and Eklund [2008, 2010]	0,148
Gong, YG. and Chen, X. (2010)	0,193
Brzeziński et al. (2011)	0,110

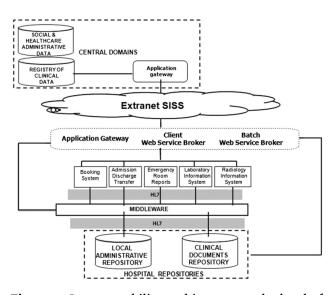


Figure 2: Interoperability architecture at the level of health organization (hospital) and its relationship with the regional information system (Barbarito et al.; 2012)

architecture design is related to the patient's identifier. Citizens should be identified preferably by the CNS. From the information provided by the authors, data stored in the Central Repository of Social & Health Administrative Data, shown in Fig. 3, is very similar to the data from the Primary Care Registry (PCR) which is an extension of CNS. One of the functional requirements of the architecture is to ensure administrative data at the health organization level are synchronized with a central citizen registry, which contains up-to-date information of all citizens in the region, to avoid erroneous or duplicate data

(Barbarito et al.; 2012). Thus, the local administrative data repositories and the municipality's central repository of administrative data must remain synchronized. They may contain PCR data as well as other administrative data. These repositories should ideally stay synchronized with CNS base, connecting through its SOA Bus, so that they can keep up-todate data pertinent to the CNS.

6.1 Architecture Use Scenario in Brazil

Fig. 3 illustrates how the proposed architecture can be implemented to allow technical interoperability between two EHR systems, one in a UBS and another in a hospital.

In this architecture use scenario, the front-end application used by the clinician requests a web service to the CWSB, which forwards the web service call to the service provider (1), in this case, a service of the Central Registry of Clinical Data (CRCD). The CRCD then sends EHR location data (Unique Identifier - EHR URI) (2) as a response to the frontend application. With this information, the frontend application sends an EHR request to the AG of the hospital where the EHR was generated and is currently stored (3). Before submitting a request to the local hospital repository, the hospital's AG verifies that the clinician has access right to the specific EHR (following established privacy criteria) by using the VPC of the central domain (4). If the access right is verified, the central domain acknowledges the request (5), and the AG sends an

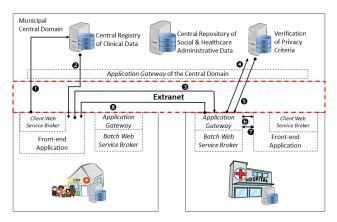


Figure 3: Interoperability at the municipal level

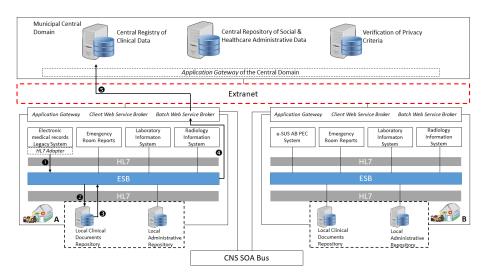


Figure 4: Interoperability at health organization level

EHR request to the local hospital repository (6). Then, the hospital repository management system delivers the EHR to the AG (7), which sends the EHR to the clinician's front-end application through Extranet

According to Barbarito et al. (2012, 2015), HL7 adapters provided by JCAPS (Oracle; n.d.) allow legacy systems to interoperate. In addition, the authors report documents and messages exchanged between systems were standardized by region. Let A be an EHR legacy system in a UBS, let B be the e-SUS AB PEC system in another UBS, as shown in Fig. 4.

The system of the UBS "A", using an HL7 adapter, can generate documents encapsulated in HL7 messages. In the Brazilian scenario, it can generate the RAS document in XML format standardized by Datasus [11], the same document format used by the e-SUS AB PEC system. The system, encapsulated as a service, sends these wrapped documents in HL7 messages, through the ESB (1), to the local clinical data repository (2). Each time the local clinical data repository receives an EHR, it sends a link store request in the central register to the BWSB (3) that forwards the request to the CRCD (4) (Barbarito et al.; 2012). Since the EHR links of the UBS A are stored in the CRCD (5) they are accessible to the UBS B, as described in the previous scenario of Fig. 3.

6.2 Architecture Implementation Remarks

During the evaluation of the proposed architecture, a drawback was noticed regarding support to update of standards. In order to provide interoperability among systems, specific adapters were used for the HL7 standard. Crichton et al. (2013) architecture presents a remarkable aspect of being independent of any data/message transfer standard. The standard to be used is encapsulated in normalization and denormalization routines, fostering standard upgrade or change. The architecture proposed in this work should normalize and de-normalize routines like Crichton et al. (2013) architecture, instead of using HL7 adapters, since this standard may fall into disuse, being replaced by another standard, such as FHIR.

Another shortcoming found in the architecture

during evaluation was the low cohesion of CWSB and AG components which have several responsibilities. To solve this problem, at the implementation phase of the architecture, these components should be divided into sub-components, where each one has a small and focused set of responsibilities, thus facilitating architecture maintenance.

To ensure architecture reliability, a protocol such as WS-ReliableMessaging can be used, as it provides a framework capable of ensuring that service providers are notified of the success or fail over message transmissions. To ensure availability, it is recommended to create a service level agreement, which specifies obligations of parties involved (customers and service providers). A service level agreement also specifies measures to be considered in case of deviation or failure, such as availability and response time (O'Brien et al.; 2007).

6.3 Discussion

Architectures that use distributed EHR repository paradigm, like the architecture proposed in this work, increases network traffic as the number of clients increases. In this way, a shift from the distributed architecture paradigm to semi-distributed one is suggested, where summarized EHRs are stored in a central repository along with links to their full versions. Then, the health professional will be able to see the patient's summary medical history and thus, be able to extract the complete EHR data from remote health organization as required (AlJarullah This change would make and El-Masri; 2013). the architecture even more suitable for Brazilian public health organizations since a RAS document is generated for each patient care at a computerized UBS. In the near future, a RAC document is supposed to be implemented. So, a summary record is already being generated for each care and a complete record of each care will be stored locally in health organizations (Brasil. Ministério da Saúde; 2016b). This change, however, does not only lead to changes in the EHR repository. As we can see in the usage scenario, when requesting EHRs available to a citizen, the web service of the CRCD sends data without performing an access control, i.e., without calling VPC service. This happens because only links are sent and from the links, the health professional requests the access to the document and only at this moment, the access right is verified. The shift to the semi-distributed paradigm requires study because it generates change in the message flow and perhaps the creation of other components in the architecture.

In order to reduce architecture implementation costs, JCAPS could be replaced by OpenESB, which is an open-source project developed from the same source code as JCAPS (OpenESB; 2016), or another open-source ESB such as Mule, which is used by several researched architectures.

Conclusions and Future Work

This work proposes a solution to provide technical interoperability among EHR systems in Brazilian public health organizations based on an evaluation, using the AHP method, of different interoperability architectures proposed in the literature.

The application of the architecture of Barbarito et al. (2012, 2015) at the municipal level allows providing technical interoperability isolated systems that currently operate in public organizations and sharing EHRs between these organizations. The study of this architecture and the use scenarios analyzed in this work showed that it is generic enough to be adopted by diverse Brazilian cities and flexible to changes, which allows adapting it to reduce implementation costs and enable its use in the health scene of Brazil.

The architecture integrated with the CNS SOA Bus can bring great benefits to the Brazilian health organizations and to the patients, such as sharing and integration of health information and the availability of the complete EHR of the patient in any health organization in which he/she receives medical attention, reducing data redundancy and rework. Other countries can use this study to evaluate technical interoperability solutions in their health organizations, if they adopt the same technologies or even if they adopt different SOA technologies, where it would only be necessary to change the first evaluation criterion which is compliance with the country's legislation, which deals with the technologies approved by the government.

Detailed studies must be done in order to evaluate EHR repository shift from distributed to semi-distributed to improve the scalability of the architecture and better fit to RAS and RAC document The organization of the architecture's services into smaller tasks to be assigned to software agents is also required, in order to improve maintainability, reuse and reduce implementation time. Architecture adaptation to cloud computing is also suggested as it may be adopted by e-PING.

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