Middleware For Heterogeneous Healthcare Data Exchange: A Survey

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Abstract — In this paper, we present a survey for data exchange middleware in health based on the HL7 standard. HL7 is an international standard, grounded on the Open System Intercommunication model (OSI), which standardizes exchange and transportation of information between healthcare organizations. Based on this standard, we examine examples of middleware selected during an exploratory research in the repositories of the Association for Computing Machinery (ACM) and Institute of Electrical and Electronics Engineers (IEEE). This article provides an overview of features present in the selected middleware.

Keywords - Middleware; Healthcare; Data Exchange; Interop; Heterogeneous Data; HL7; EHR;

I. INTRODUCTION

Healthcare systems produce a huge amount of health data. In most cases, information is spread among public and private institutions, clinics, care centers, laboratories, etc. One of the big challenges in the medical area is to provide access to patient's clinical data, regardless of where they were generated [1]–[3]. There are architectural models which standardize storage and communication of electronic healthcare records (EHR) – e.g. OpenEHR [4] and EN 13606 [5][6]. However, even solutions that have their working repositories implemented based on one of the previously mentioned models use different types of database or technologies, are in different versions or have other particularities that make them different from the others [7].

In the data exchange domain, there are various technologies that address the task of exchanging information between heterogeneous databases, such as Web-Services [8] and Cloud Services [9]. However, according to Xianyong Liu [10], middleware represents a technology that takes charge of communication and bridges lower-level Data Transfer Units.

For this paper, we discuss the already available HL7-based middleware, ongoing research projects and solutions under development for HL7-based healthcare information exchange. We conducted a literature review and selected two works which and will be henceforth named Middleware A and B. The other middleware analyzed represent solutions that are present on the IT market, which are Mitre hData, Mirth Connect and IBM Websphere [11]–[13]

Health Level-7 (HL7) refers to a set of international standards to transfer clinical and administrative data between software applications used by various healthcare providers. These standards focus on the application layer, which is "layer 7" in the OSI model [14][15]

The main objective of this work is to discuss the already available HL7-based middleware, as well as ongoing research projects and solutions under development for HL7-based healthcare information exchange. Section II discusses some aspects related to HL7 and healthcare systems. Section III presents the types of middleware and indications of use for each one. Section IV discusses projects and applications of HL7-based middleware and shows a comparison between them. Finally, conclusions and future developments of this research are presented in Section V.

II. HL7 AND HEALTHCARE SYSTEMS INTEGRATION

HL7 was founded in 1987 with the objective of defining standards for information exchange between health systems. It is a non-profit institution approved in 1994 by the American National Standards Institute (ANSI) [16]. The standard follows the conceptual definition of the application interface model, represented by the seventh layer of the OSI model, providing support to plug-and-play functionalities when used to integrate two or more health systems [17].

The HL7 standard provides specifications aiming to standardize the exchange and transportation of information between health systems, with the objective of making such systems interoperable [18]. HL7 is highly recommended to organizations seeking interoperability between internal and external systems of public health. The standard provides quality, efficiency and effectiveness in the delivery and sharing of medical information [17].

The HL7 standard encompasses groups of specification, like the ones exemplified below:

- Message protocols for the information exchange between health systems;
- Clinical Document Architecture (CDA) for document exchange.

A. Tools that use the HL7 standard

HL7 can be used for diverse implementations of health systems integration. Some of them were identified and described as follows:

- Implementation of test middleware to validate the formats of messages in the HL7 standard, allowing for the identification of a system that does not comply with the HL7 standard [19];

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- Implementation of an emergency medical system using the Open Services Gateway Initiative (OSGi) service platform, enabling sharing information between medical systems and emergency services. This system uses the HL7 standard to format messages;
- Implementation of a mobile app that receives data from medical sensors and converts them to the HL7 standard so they can be sent later through the Wireless Local Area Network (WLAN) or Bluetooth. It can receive diagnoses and prescriptions later;
- Implementation of middleware to standardize the communication between different types of medical devices and health systems. It is made possible by converting the IEEE 1073 standard, when the medical devices follow the HL7 standard [17];
- Application that receives data from devices that measure vital signs, such as blood pressure, heartbeats, levels of glucose and body temperature. These pieces of data are received by the communication interfaces of the device, i.e. Universal Serial Bus (USB), Bluetooth or WLAN. All data is received by the application in different formats and then sent to the telemedicine central in the HL7 standard to be analyzed. When it becomes possible to provide more detailed care, the central activates a videoconference to detail and explain the situation to the caretakers in charge [20].

III. MIDDLEWARE

As a way to solve issues related to health information exchange, we analyze the middleware technology. It is a technology for distributed applications, able to hide details of the network and deal with a great amount of important functionalities for development, implantation, execution and interaction of applications [21]. The main idea is to be between two layers enabling communication between the connected parts. It is not only a network application which connects two sides, but also a means to promote the interoperability between the applications, protecting implementation details of functionalities and providing a set of interfaces to the customer [10].

There are various types of middleware that can be implemented with the objective of providing the exchange of health information, e.g. transactional, procedural, message-oriented and object-oriented.

A. Transactional Middleware

The transactional middleware (TM) is designed to provide synchronous distributed transactions [22]. It consists of a transactional monitor that coordinates simultaneous transactions between customers and servers, reducing the overload, response time and Central Processing Unit (CPU) costs between the components by guaranteeing the Atomicity, Consistency, Isolation and Durability properties (ACID). However, they offer unnecessary and undesirable warranties through the ACID properties. When a customer is performing a long processing, it may prevent other customers from following up with their requests [22].

As there is always the need to exchange a great number of health messages, each customer will always have a great amount of information to be shared, rendering this middleware inappropriate for this objective.

B. Procedural Middleware

The procedural middleware (PM) was developed by SUN Microsystems around the decade of 1980 and became known as the Remote Procedure Call (RPC). Its implementation is supported by various computing environments; however, they do not offer good communication because they do not support asynchronous transmission, replication or load balancing [22].

C. Message-Oriented Middleware

Message-oriented middleware (MOM) allows for distributed applications to communicate and exchange information by sending and receiving messages [23]. The essential elements for a message-oriented middleware are clients, messages and the MOM provider, as seen in Figure 1, which depicts an API and administration tools [23]. This middleware exchanges information asynchronously.

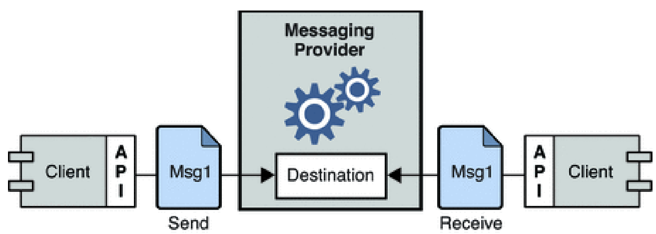

Figure 1. MOM-Based System [23]

This way of working provides the customer with the means to continue working even if a message has been sent – it doesn't make customer wait for a response. However, it might run out of message storage resources, which can generate a failure in the component. The HL7 international protocol predicts the exchange of information through asynchronous messages, which makes this type of middleware the best for implementing a solution for the health information exchange. Some examples that may illustrate this modality are Microsoft Message Queuing (MSMQ) by Microsoft, [24] and MQSeries by IBM [25].

D. Object-Oriented Middleware

The object-oriented middleware (OOM) allows applications to communicate and exchange information by invoking methods [26]. It works precisely like the local method invocation. Its communication is synchronous, which means an object invokes a middleware method and awaits the response of said method. Similarly to Peer-to-Peer and Remote Procedure Call (RPC) communications, this

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workflow prevents the client from using the system while the invoked object is working.

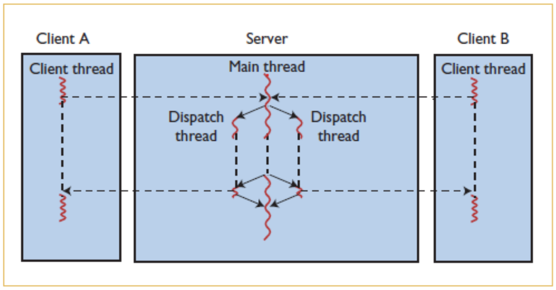

Figure 2. Synchronous call [26]

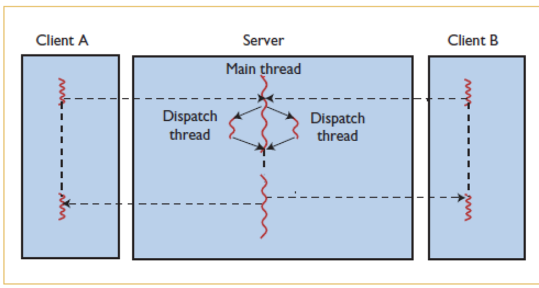

Figure 3. Asynchronous call [26]

A great advantage of the object-oriented middleware is the fact that it accepts the invocation of methods written in different programming languages [26]. Moreover, some OOM support both synchronous and asynchronous messages; this is an attempt to mitigate the limitations caused by one form of communication. Other OOMs also implement types of message exchange control in order to use resources more efficiently, by making use of threads and timeouts [26]. Figures 2 and 3 illustrate this behavioral change in Messaging.

IV. HL7-BASED MIDDLEWARE ANALYSIS

The middleware analysis based on characteristics present in the construction of each middleware was separated into ten categories:

- Synchronous: when the middleware supports synchronous messaging;
- Asynchronous: when it supports asynchronous messaging;
- Type of Middleware: if the middleware is TM, PM, OOM or MOO;
- Web Bases: when the middleware runs uses web architecture;
- HL7 v2.x: when it supports any version 2 of HL7;
- HL7 v3.x: when it supports any version of HL7;
- HFIR: when it supports HL7 HFIR versions that combine the best features on v2, v3 and CDA;
- Parsing: when it offers the process to message syntactic analysis;
- Validating: when it offers the process of verifying the message conformance;
- Transmitting: when it offers the process of submitting the message to other client.

A. Middleware A

In [16], Liu et al. proposed an extensible HL7-based middleware, as shown in Figure 4, to provide a communication channel between different healthcare information systems that either did not support HL7 messages exchange or had not implemented an interface for it yet.

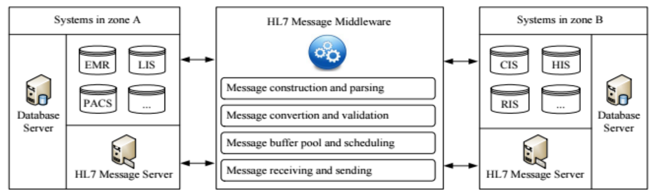

Figure 4. HL7 middleware architecture

This middleware has three deployment options: client-side, server-side and independent deployment., although only the independent deployment uses all the HL7 functions.

B. Middleware B

Ko et al. [27] presents a middleware framework developed for the National Taiwan University Hospital (NTUH). Figure 5 shows that it consists in a multi-tier service oriented architecture (SOA). It uses the message and event type to identify the required service and invoke the correspondent sub-routine. HL7 messages are used to format all information exchanged across systems.

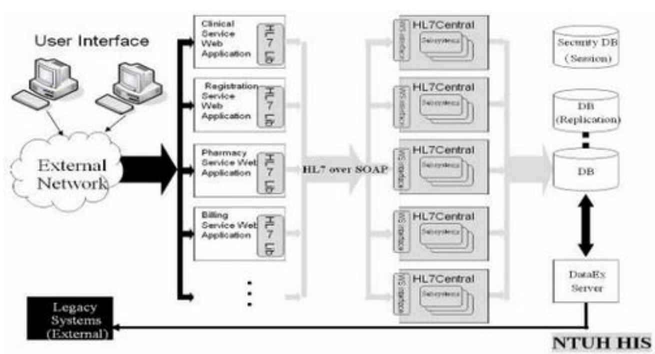

Figure 5. NTUH HIS system architecture Note

Besides the conventional middleware presented above, there are extensible libraries and components that address the complexities of HL7 encoding and decoding rules along with acknowledgements, allowing for the application developer to focus on underlying business logic and workflow, such as Merge HL7 and HAPI-Fast Healthcare Interoperability

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Resources (FHIR) toolkits. Furthermore, there are specific tools for parsing and transmitting HL7 messages, e.g. HL7Spy and HL7 Analyst [28]–[30].

C. *Mitre hData*

Donald W. Simborg created the Level 7 protocol originally (in 1977), which later turned into the well-known HL7 standard version 2. He was developing departmental systems at the Johns Hopkins University, in Baltimore, MA, and was programming in the APL language. He continued to develop systems at the University of California in San Francisco (UCSF) in 1976, where his CIO was. Besides, he also worked for Mitre Corporation, a think-tank company of California where he acquired a lot of experience in the pioneer use of LANs and High Level Protocols (HLP) protocols [13].

hData is a standard for electronic health data exchange which is WEB-based and very light. Formulated in 2009 by MITRE and a non-profit organization, it has since evolved through the cooperation of the leaders in the health industry. The hData standard is the first one developed for RESTful health data exchange. Figure 6 explains the composition of hData.

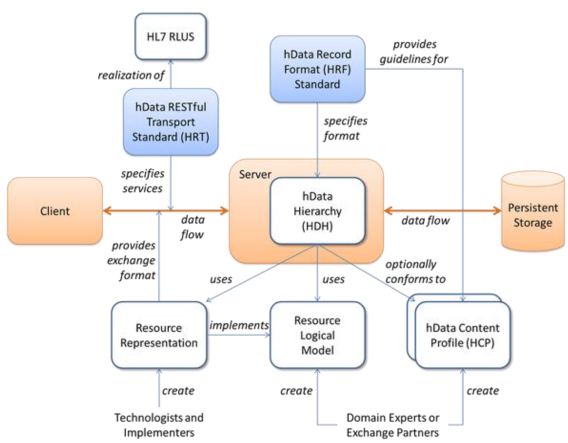

Figure 6. Relationship between the different components of hData [13]

The hData Registry Format (HRF) specifies the format of the hData Hierarchy (HDH). HDH is based on models of logical resources provided externally by experts in the domain or partners in the exchange of information, e.g. FHIR. HDH may be satisfied with one or more hData Content Profiles (HCPS), which are guides for the implementation and use of hData in specific domains. The server that hosts the HDH instance provides a service interface for the customers to interact with the HDH resources, placing information in persistent data storage. The hData RESTful Transport (HRT) standard specifies these services if there is a REST implementation.

D. *Mirth Connect*

Created by Mathias LIN, it is a middleware considered the Swiss army knife of the integration engines of health information. It is specialized and designed to exchange messages in the HL7 standard and counts on tools to develop, test and monitor interfaces [31]. Figure 7 illustrates an architectural vision of a system that uses Mirth Connect.

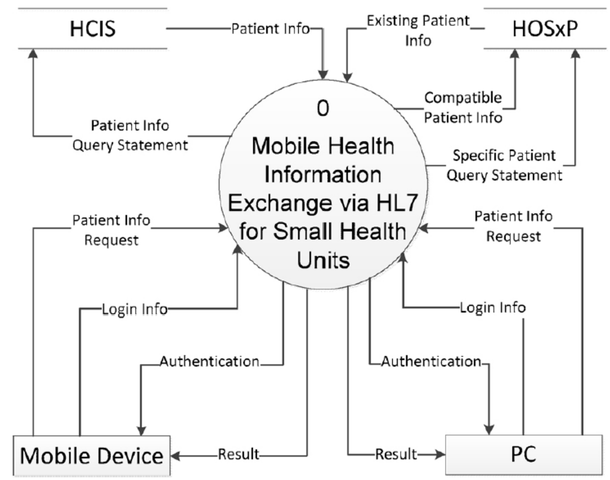

Figure 7. Architecture of a system using Mirth Connect as a Middleware [11] .

The following functionalities are available:

- A rich interface channel development and monitoring environment using an intuitive drag-and-drop template-based editor;
- Real-time connection monitoring through a dashboard;
- Message reprocessing;
- An integration server that supports a variety of protocols to connect to external systems, and diverse database options.

E. *IMB WebSphere Message Broker*

The IMB WebSphere Message Broker (WMB) is considered a product of business integration and used to integrate applications of general purpose by applying message transformation, enrichment and routing. It supports health applications even if they were built in other languages, such as .NET, C or Java. Figure 8 depicts the architecture of a WMB application.

WMB offers:

- Models of message used to analyze, route and transform HL7 messages;
- Input and Output nodes to integrate HL7 clinical applications;
- Integration with medical devices;
- Integration with Digital Imaging and Communications in Medicine (DICOM);
- Specific standards of medical assistance;
- Operational monitoring of data transmission for medical applications;
- Generation of events of Audit Trail and Node Authentication (ATNA) auditing to support

confidentiality of patient information, data integrity and provision;

- Ability to extract information from medical assistance data in message flows, and sending information.

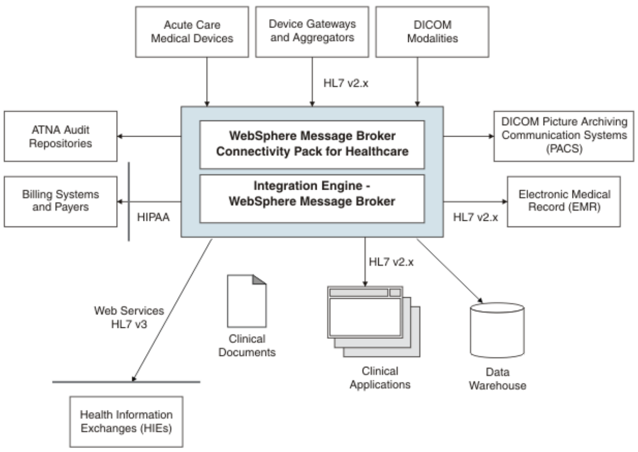

Figure 8. Architecture of a health system using WMB [12]

The selected characteristics of the presented middleware are summarized in Table I.

TABLE I. CHARACTERISTICS OF PRESENTED MIDDLEWARE

Characteristics	Mid A	Mid B	Websphere	Mirth Connect	hData
Synchronous	x	x	x	x	-
Asynchronous	-	-	x	x	x
Middleware type	MOM	MOM	MOM	MOM	MOM
Web-based	-	x	x	x	x
HL7 v2.x	x	x	x	x	-
HL7 v3.x	x	-	x	x	-
HFIR	-	-	x	x	x
Parsing	x	x	x	x	x
Validating	-	x	x	x	x
Transmitting	x	x	x	x	x

Table I shows the features supported by each middleware evaluated in this work. Observing the results obtained, it is possible to highlight the following points: i) all middleware analyzed are MOM types, ii) all of them encompass all methods of parsing and transmitting, iii) only the market middleware supports HFIR and asynchronous message exchange.

V. CONCLUSION AND FUTURE WORK

In this paper, we have analyzed and compared different middleware for healthcare data exchange. This study showed the extensibility of HL7 standards and the ongoing HL7-based projects and research. The comparison analysis provided an insight into the strengths and weaknesses of the middleware architecture, the compatibility with HL7 versions, operating systems, architecture, features and connection type. Based on the survey, we found that the Mirth Connect and Mitre hData middlewares are the most appropriate for exchanging health data. This is due to the fact that they present features which are more compatible with the HL7 standard, as both middlewares are specifically meant to be used in health applications. The Websphere middleware, for general purposes, may also be used in health data exchange. However, the lack of alignment with the HL7 standard would increase the complexity of the developed solution.

In future works, we will use a HL7-based toolkit to implement, test and measure a middleware to integrate different healthcare solutions and consolidate patient data in a big-data repository using HL7 messages. Then, we will compare the results with the existing middleware and, depending on the results, propose a new HL7-based middleware architecture.

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