Abstract

Information systems in healthcare are complex abstract systems. Systems communicate in a consolidated manner. Several methodologies exist presently to implement interoperable information systems in healthcare. It results in several common communication architectures and mainstream standards such as Health Level 7. However several concerns regarding distribution, fault tolerance, standards, communication flavoring and tightly bound systems still exist broadly throughout the healthcare arena. The multi-agent paradigm has been an interesting research opportunity for addressing many of such limitation in interoperability. It allows orientating agents towards adaptable but standardized information flow enabling interoperability in a loosely coupled manner.

This paper proposes and explains a multi-agent based architecture, which uses the HL7 standard as a means towards the implementation of interoperability in healthcare environment. It follows the concept of distributed consolidation of information, aiming heterogeneous systems to communicate towards their mutual benefit however through middleware agents which validate and consolidate information.

Keywords: Type your keywords here, separated by semicolons ;

1. Main text

Due to its specificities, the healthcare information system configures an environment composed of intricate information technology systems, in which distinct solutions must share data and information consistently and
as a whole. The exchange of data and information is of the essence for the optimisation of existing resources and the improvement of the decision making process through consolidation, verification and dissemination of information. Henceforth, within the healthcare environment the integration of all otherwise secluded applications is of the essence for the development of a scalable and functional Health Information System (HIS). The HIS is foremost the consorted and integrated effort of the different heterogeneous solutions within the healthcare institution to collect, process, report and use information and knowledge related to its unique environment to influence the existing management policies, health programs, training, research and medical practice within this institution [4]. The core concept of a HIS as an abstract global information system for the processing of data, information and knowledge within the healthcare institution, indicates the significance of interoperability between systems in healthcare.

Numerous architectural solutions have been developed towards interoperability in healthcare, depending of the objectives, context and methodological approaches. At this architectural level, one can enumerate distinct and relevant abstract interoperability approaches, such as end-to-end, hub-and-spoke, distributed multi-agent or service oriented. Properties such as modularity, availability, scalability or delay timespan are associated to the interaction of different systems comprised in the devised architecture.

Considering the definition of an HIS, its essence is the architectural model composed of a group of integrated and interoperable solutions within the healthcare institution. In contrast with the usage of a centralized solution, which is unthinkable considering the specificities of each areas of a healthcare unit, it aims to maintain all distinct services and solutions. It is henceforth essential to imbue the HIS architecture with the capacity to allow communication among different and otherwise secluded systems, avoiding their centralisation and dissemination of End-to-End connections, which restrict the growth of all the infrastructure associated to the HIS. The non-modularity of services adds complexity to alterations and improvements, increasing the global costs of the information systems [1]. Therefore, it is understandable the present concern demonstrated by distinct international institutions, responsible for financing and regulating the purchase and development projects for new HIS, with matters of flexibility, interoperation and integration of heterogeneous systems [2] [9].

Congruently with these concerns, present tendencies regarding research and industry in interoperability applied to healthcare information systems, indicate the potential of agent-oriented architecture [3] [6]. Asides from modularity, scalability and adaptability these systems have also the potential to imbue new features associated to intelligent agents, which may address the existing problems and solve important limitations otherwise difficult to tackle [7]. Although healthcare standards like HL7 are completely distinct from agent communication standards, HL7 services can be also implemented under the agent paradigm [8]. These agent based HL7 services can communicate with services that follow distinct paradigms and communicate with other agents using either HL7 or agent communication standards. Although the HL7 standard can be implemented using other architectures, agent-based solutions enjoy of a vast interoperability capability, being capable to be embedded with the most particular behaviours. These behaviours can become increasingly effective if they use machine learning and other artificial intelligence techniques in order to adapt to the existing environment and being able to prevent errors and correct the flow of information and extraction of knowledge within the institution.
2. Health Level Seven Protocol

Health Level Seven HL7 gave its first steps as a syntactic healthcare oriented communication protocol at the application layer, the seventh layer of the OSI communication model. The initial versions of the protocol defined the message structure to be exchanged by loosely connected healthcare applications by classifying the different types of messages involved in this environment which were composed at its core by the aggregation of standardized segments.

Henceforth the aim of HL7 is centered on the syntax of what is exchanged, rather than the technology or mean by which this communication occurs nor the underlying architecture. However considering the objective of the communication and the structuring and design of this standard, defining which artefacts of data should be transferred by a certain message and the events, which should be, be subsequent, the application of client-server architecture was potentiated. In fact, the most common implementation of this architecture using HL7 is based on distinct socket communication clients and servers, in which the client sends an HL7 structured message to the server, that upon processing sends an acknowledgement HL7 standardized message. As mentioned before the HL7 standard is not bound to any technology or either to this architecture, but it is the most widely used in healthcare interoperability.

The initial versions of HL7 were uniquely syntactic, and according to the general models of interoperability are one of the lowest levels of this process. The current version 3 is opening the HL7 scope towards semantic interoperability, including the appropriate use of exchanged information in the sense of the communicating applications behaviour. This model presented in version 3 contains relations and metadata in a abstract level that may enable far higher levels of integration, namely by semantic interoperability and validation of exchanged information, using the relational mapping of each artifact. The Message Development Framework (MDF) is currently moving towards the HL7 Development Framework (HDF), therefore shifting the HL7 paradigm from message to architecture. Newer HL7 developments such as the EHR-S Functional Model and the SOA Project Group activities have been pushing this move [5].

The metadata and archetypes defined in HL7 allow it to organise both production and clinical data in clearly defined and connected segments and fields, which can be validated among artifacts. However, the implementation of version 3 is still rather limited as few service providers and institutions migrated already to this version.

Although version 3 presents several improvements from the previous version, the latter is still the most commonly used in healthcare information systems and equipment. The messages in this version are defined and identified by its control segment. In the control section of the HL7 standard several rules that are applied to all messages are defined:

- Message Segment
- Message Type
- Trigger Events
The core principle underneath the usage of this approach is the principle that behind any practical event there is the requirement for data to flow among heterogeneous systems that comprise the HIS. Henceforth, most events on the healthcare environment act as triggers for the initiation of information dissemination. While an event can emerge at one system and be handled by this system alone, being the flow of information to other ones aimed mostly at maintenance of consistency; an event can be initiate at one system but need to be handled by another, in which case the information transaction is named an unsolicited update. The scope of the standards aim is to solely specify messages between systems and the events, which trigger them. No considerations regarding underlying systems architecture and implementation are concerned by HL7.

A trigger event may come from one of the following sources:

User Request Based (in this document also referred to as Environmental) - For example, the trigger event that prompts a system to send all accumulated data to a tracking system every 12 hours is considered Environmental. Similarly a user pressing a button in a user-interface would be considered environmental

State Transition - resulting from a state transition as depicted in the State Transition Model for a particular message interaction. The trigger for cancelling a document, for example, may be considered a State Transition Based trigger event

Interaction Based - based on the receipt of another interaction. For example, the response to a query (which is an interaction) is an Interaction Based trigger event.

From this perspective the flow of information between all information systems and elements in the healthcare institution, or by other words the entire HIS is governed by these events. Its the paper of this standard to regulate ad defined all these events as well as their implication and required information for the underlying procedures.

The fact that most of the communications are currently being performed with a syntactic and flavored norm such as HL7 version 2 results in loss of modularity and inherent stronger coupling than desirable between systems. Moreover the complexity of flavoring and specificities of each interoperation among systems restricts a standard and extended evaluation of the information within the message before disseminating it among all the systems which compose the HIS.

Although other standards and technologies such as HL7 version 3 or openEHR allow further semantic reasoning and validation, its implementation in real environment is far from a solution considering the difficulties of dealing both of legacy systems or flavored approaches. Moreover the efficiency of the piped HL7 under version 2, and its optimisation over the years turns the migration to these more complex standards and technologies (e.g. XML) far more intricate as it can result in a overhead in equipment and systems communication.

A rather more technological but also significant source of problems is the existence of unpredictable communication failures in the network associated mainly with the hours of higher production rate.
3. Multi-agent systems for interoperability

The multi-agent system paradigm has been an interesting technology in the area of interoperability in healthcare. Being multi-agent architectures a field of research of distributed artificial intelligence, this technology is intrinsically connected to the basilar concepts that define a distributed architecture, while being distinct in the intrinsic definition of an agent versus the properties of the general middle-ware of many others distributed architectures. Being distributed by nature its characteristics introduce MAS as a rich and fiercely adaptable technology with great interest mainly due to the research interests in this arena.

In an environment where the demand for middle-ware both for production and legacy systems are constant, the agent paradigm demonstrates an intuitive advantage in organizational development in terms of creation of such services.

In this research area concepts and technologies such as terminologies, ontologies, mobility, failure recovery and intelligent behaviours are embedded or explored in many existing frameworks. Henceforth they are of interest for healthcare interoperability and a tool towards intelligent interoperability systems.

4. HL7 services in multi-agent system

As mentioned before the HL7 standard does not limit the usage to any technology or architecture, however being the objective of its usage to regulate communications in healthcare oriented systems, there are obviously technologies and architectures that became the most used. Henceforth, the technologies and architectures that grew more common are the ones that are present by default from information systems to specific equipment for the execution of diverse complementary diagnosis methods.

However exchange of communication is not solely limited to occur between information systems, as communication with equipment is ever-growing more important. This fact is very important to consider since it implicates that not only information systems are concerned with standards and technologies when dealing with communication, the equipment must as well deal with such characteristics. This equipment usually either communicates through the usage of standards in a loosely-coupled manner, i.e. directly with an information system (Radiological Information System, Cardiological Information System,...) or with a proprietary system which can in its term be compatible or not with other information systems. This sort of equipment usually follows a client/server architecture, in which the equipment is in most cases solely a client.

From what is understandable from these last paragraphs there is a considerable difficulty in creating a system that uniformly understands and communicates fully with all services within a HIS. As explained before the even with the overall adoption of standards, more specifically HL7, different flavorings usually require a distinct handling of messages and its events. The unique characteristic of the agent parading allows creating specific behaviours or agents, which are adapted to any situation while keeping all systems loosely, coupled.

The currently detailed multi-agent system was developed under WADE/JADE and is currently in production in mid-sized regional hospital, being responsible for the consolidation and distribution of information in this environment. It is responsible for more than processing and disseminating HL7 messages;
it performs several back-office functions indispensable for the functioning of the HIS. However, for the scope of this paper only the HL7 related functionalities will be elaborated.

The concept aimed to represent and implement through this multi-agent system is the idea of distributed consolidation of information. This agent system consolidates in its own data model the information considered relevant for all information systems. When a HL7 event is received through any server agent, it is pre-processed and forwarded to another agent ready to handle this message and its events. The consolidation of this information generates events that are disseminated as HL7 events and messages throughout the systems that are registered as servers in the parametrization of the multi-agents system.

An HL7 server agent may receive messages from several clients, depended or whether or not the client keeps the connection open even while not sending messages or the number of ports open for the TCP pipe parser. As each agent by default in JADE is a unique thread, a sound characteristic that follows the perspective of an agent identity, a single socket pipe parser is preferred per agent, however the pre-processing of each message is handled as a new thread by feeding the message to a behaviour which is encapsulated in a ThreadedBehaviourFactory object. This methodology is preferred not to lock the agent’s life cycle, to process the message immediately and to grant that the socket is freed as soon as possible.

Figure 1 - Information flow inherent to the developed HL7 service using a multi-agent system
As demonstrated in Figure 2 there are several containers with agents to receive and process messages, however the organisation per container is not significant. Analyzing the server agent in greater detail, its behaviours are orientated solely with the forwarding of a specific message and event to an agent prepared to provide these services. According to parametrisation of the MAS, the messages are forwarded to agents responsible for dealing with the service which sent the message and the specific event. Such agents are easily found by the use of a common ontology that defined not only agent communication but also details pertaining the services registered at the directory facilitator, so that the server agent can easily find the agent the message must be forwarded to. This dynamic information flow allows to have a set of genera processing agents as well as to add and remove specific agents when needed for a specific interoperability service. Moreover throughout this methodology only the server agents need to be fixed to a specific container and machine, the agents that process the messages and have most of the workload, can have mobility and move from machine to machine, container to container as necessary and also be created more than one agent for the same description service, distributing load and enabling failure prevention.

The consolidation of information is achieved by the conversion of HL7 events to an ontology that also represents the consolidation model present in the relational database. This allows the ontology objects to be handled directly in synchrony and congruently with the database. For this purpose the basic JADE framework as extended with a hibernate implementation significantly different from the standard made available.

From the processing and consolidation of received events the need usually occurs for client agents to communicate with other information systems in order to disseminate it. These tasks for the client can either
emerge from requests by agents that process and consolidate the information resulting from an event or form the consolidation process itself. The relational database when altered possesses a set of triggering for certain events according to parametrization, which may create tasks for the client agents.

Considering this architecture there is obviously a shift from the usual end-to-end architecture, in which services directly intertwine with each other creating a complex mesh of connections. This architecture aims to turn the services available at the HIS loosely-coupled to an extent that adding or removing a service is a matter of changing parametrization within the multi-agent system or add a specific agent type that handles communication translation to a standard one. If a information system is removed or fails to respond the meaningful information remains stored at the consolidation database, while events that will consolidate the system with the rest of the his are being stored and scheduled in this same consolidation database.

5. Conclusions

The usage of multi-agent systems in interoperability problems constitutes a significant research opportunity to improve the communication among heterogeneous systems. Several of the research interests of agent technology such as ontologies, mobility and fault tolerance among many others can be of great use and interest to be applied in this area.

Although this module represents solely a part of greater project aimed towards a HIS with enhanced forms of interoperability, it is of great significance and interest as HL7 is the most common standard for healthcare communication among heterogeneous systems. This module is currently under validation being introduced gradually into the production MAS.

The most important characteristic of this architecture and model is that instead of a mesh of end-to-end system communication or a major centralisation of processing, this paradigm is by nature distributed but allows a consolidation of processual and clinical validation of information. This consolidation is of the essence for the establishment of a complete electronic health record in an environment in which heterogeneous information systems exist.

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