Interoperability in Health Care

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ABSTRACT

With the advancement of technology, all patient information has been being computerized in order to facilitating the work of healthcare professionals and to improve de quality of healthcare delivery. However, there are many heterogeneous information systems that need to communicate so as to share information and to make it available when and where it is needed. To respond to this requirement it was created the Agency for Integration, Dissemination and Archiving of medical information (AIDA), a multi-agent and service based platform that ensures interoperability among healthcare information systems.

In order to improve the performance of the platform, beyond the SWOT analysis performed, it was created a system to prevent failures that may occur in the platform database and also in machines where the agents are executed. It was possible conclude that in the Centro Hospitalar do Porto, the critical workload of AIDA is the period between 10:00 and 12:00.

INTRODUCTION

In Healthcare, information systems have been growing, and consequently the volume, complexity and criticism of data become more and more difficult to manage. However, despite these systems contribute to increase the quality of healthcare delivery, information sources are distributed, ubiquitous, heterogeneous, large and complex and the Health Information Systems (HIS) need to communicate in order to share information and to make it available at any place at any time. Data are stored in multiple independent structures. Therefore it emerges the need to create a global system that brings together all the islands of information shared between services. It is necessary to develop a solid and efficient process of integration and interoperation that must take into consideration scalability, flexibility, portability and security.

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 (HL7). However several concerns regarding the distribution, fault tolerance, standards, communication and tightly bound systems still exist broadly throughout the healthcare area. The multi-agent paradigm has been an interesting technology in the area of interoperability and addressing many of such limitations (Miranda et al., 2012; Miranda, Machado, Abelha, & Neves, 2013).

The homogeneity of clinical, medical and administrative systems is not possible due to financial and technical restrictions, as well as functional needs. The solution is to integrate, diffuse and archive this information under a dynamic framework, in order to share this knowledge with every information system that needs it. So it is presented AIDA – Agency for Interoperation, diffusion and Archive of Medical Information. AIDA is an agency that supplies intelligent electronic workers called proactive agents, in charge of some tasks, such as communicating with the heterogeneous systems, sending and receiving information (e.g., medical or clinical reports, images, collections of data, prescriptions), managing and saving the information and answering to information requests (J Machado et al., 2010; Miranda, Duarte, Abelha, Machado, & Neves, 2010; Peixoto, Santos, Abelha, & Machado, 2012).

With the growing importance of HIS, databases became indispensable tools for day-to-day tasks in healthcare units. They store important and confidential information about patient's clinical status and about the other hospital services. Thus, they must be permanently available, reliable and at high performance. In many healthcare units, fault tolerant systems are used. They ensure the availability, reliability and disaster recovery of data. However, these mechanisms do not allow the prediction or prevention of faults. In this context, it emerges the necessity of developing a fault forecasting system. It is necessary to monitor database performance to verify the normal workload and adapt a forecasting model used in medicine into the database context. Based on percentiles it was created a scale to represent the severity of situations (Silva et al., 2012).

The AIDA implemented at Centro Hospitalar do Porto (CHP), in Portugal was subjected to a Strengths, Weaknesses, Opportunities, and Threats (SWOT) analysis in order to ascertain what can be change to improve the system. This analysis can reveal what are the great strengths of the system as well as its major pitfalls. In addition, the opportunities than can be taken as advantages are highlighted and the key threats to the system are alerted (Pereira, Salazar, Abelha, & Machado, 2013).

The main goal of this chapter is to explain the importance of interoperability in the context of the quality healthcare delivery. In the background section is presented a brief introduction about interoperability and its importance in healthcare environment. The intelligent agents in interoperability section present a promising technology for interoperability implementation: the multi-agent technology. Combining the issues mentioned in the previous sections, it is presented a solution: the AIDA platform. In its section it is described its architecture as well as its database. In order to improve AIDA's performance, in the following sections it is presented fault forecasting systems either from database or from machines, which execute AIDA's agents. The database, machines and agents' workload are also presented and discussed in these sections. In the last section it is analysed the strengths, weaknesses, opportunities and threats of AIDA.

BACKGROUND

HIS around the world are in rapid transition, moving from the traditional, paper-based practices to computerized processes and systems to ensure the delivery of health care and improve the quality of the services (Weber-Jahnke, Peyton, & Topaloglou, 2012). The healthcare domain, specifically HIS have been a very attractive domain for Computer Science researchers and it is facing a growing number of challenges. HIS are at the heart of all these challenges. They can provide a better coordination among medical professionals and facilities, thus reducing the number and incidence of medical errors. At the same time, they can reduce healthcare costs and may provide a means to improve the management of hospitals (Palazzo et al., 2013).

HIS provide a composed environment of complex information systems, heterogeneous, distributed and ubiquitous speaking different languages, integrating medical equipment and customized by different entities, which in turn were set by different people aiming at different goals. Everyday new applications are developed to assist physicians in their work, but those systems are built in "silos" and they have a little impact on their environment constituting isolated information islands, that limit the flow of information, lack the ability to interact and communicate with other systems (Miranda et al., 2012; Palazzo et al., 2013; Peixoto et al., 2012; Weber-Jahnke et al., 2012).

The possibility and the need of communication is one of the main characteristics of the human beings. Similarly the HIS need to communicate and cooperate in order to enhance their overall performance and usefulness, to improve HIS, quality of the diagnosis, but mainly, to improve the quality in patient treatment. Cooperation and exchange of data and information is indeed one of the most relevant features, is the essence for the optimisation of existing resources and the improvement of the decision making process through consolidation, verification and dissemination of information (Miranda et al., 2012, 2010).

The perception of integration and interoperation must be introduced into this environment. Integration aims to gather and acquire information of distinct systems in order to reinforce or strengthen them, while interoperation concentrates on the continuous communication and exchange of information across cooperative systems. Therefore it has presented the concept of Interoperability there is no definition for this term however can be said that Interoperability is the ability of independent systems to exchange meaningful information and initiate actions from each other, in order to operate together to mutual benefit (Miranda et al., 2010). The main goal of Interoperability in healthcare is to connect applications and data can be shared and exchanged across the healthcare environment and distributed to medical staff or patients whenever and wherever they need it. Interoperability is no longer a technological option, it is a fundamental requirement for delivering effective care and ensuring the health and well-being of million of patients world-wide (Rogers, Peres, & Müller, 2010).

Interoperability in Healthcare

In the last decades interoperability and the respective implications for the delivery of healthcare has been a topic of study, and in 2003 it was found that the level of interoperability between systems in most health institutions was extremely low (Carr & Moore, 2003).

However since 1987 it was founded the Health Level Seven International (HL7). It is a non-profit organization, which the main goal is providing a comprehensive framework and related standards for the exchange, integration, sharing, and retrieval of electronic health information that supports clinical practice and the management, delivery and evaluation of health services. HL7 provides standards for interoperability with multiple objectives like the improvement of care delivery, the optimization of the daily workflow, the reduction of ambiguity and the improving of knowledge exchange between all stakeholders (HL7, 2012).

There has been an intensive effort to develop standards adapted and optimized towards improving healthcare delivery. These standards have been able to give a definite structure or shape to low level interoperability in healthcare, in a firmly established and modular manner. Among these patterns HL7 is considered the most adaptable one in healthcare interoperability. HL7 started as a mainly syntactic healthcare oriented communication protocol at the application layer, the seventh layer of the Open Systems Interconnect (OSI) communication model. The initial versions of the protocol defined the message structure by loosely connected healthcare applications by classifying the different types of messages involved in this environment with the aggregation of standardized segments. It was uniquely syntactic, and according to the general models of interoperation are one of the lowest levels of this process. In the current version (3), the HL7 is focused on semantic interoperability, including the appropriate use of exchanging information in the sense of the communicating application's behaviour. This model contains relations and metadata in an 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 artefact (Miranda et al., 2012, 2010).

Interoperability in Electronic Health Record

Nowadays information technologies in medicine and healthcare are experiencing a difficult situation in which each staff person uses in your daily work a set of independent technologies that involves very information. This independence may be the cause of difficulty in interoperability between information systems. The overload of information systems within a healthcare facility may lead to problems in accessing the total information needed.

HIS have gained great importance and have grown in quality and in quantity. With this information overload, it is necessary to infer what information is relevant to be registered in the Electronic Health Record (EHR) and Decision Support Systems (DSS) must allow for reasoning with incomplete, ambiguous and uncertain knowledge (Peixoto et al., 2012). The EHR is a core application which covers horizontally the healthcare unit and makes possible a transverse analysis of medical records along the services, units or treated pathologies, bringing to the healthcare area new methodologies for problem solving, computational models, technologies and tools.

Due to the complexity of each HIS, the possibility of a global information system emerges as something complex and incomplete. However, the need to gather significant information to be shared with other services and to communicate all relevant data related to the patient and the executed procedures, is not only of high value to the institutions, but also to the patient. In order to aggregate and consolidate all significant information, a solid and efficient process of interoperation or integration must be developed. This process must take into consideration scalability, flexibility, portability and security when applied to EHR. The complexity and sensitivity of the exchanged information require more than technological efficiency and pragmatic exchange of information. The dissemination of incoherent information and its introduction into the EHR may cause more than inconsistent records, they may give rise to a wrong diagnose. In order to avoid this moral and ethical drawback a thorough validation of the exchanged and integrated information must be performed. The development of top-level interoperability frameworks is henceforth of an intrinsic nature or indispensable quality of the healthcare environment. The multitude and intricacy of services that must be performed by the EHR and Group Decision Support Systems (GDSS) require such a framework or otherwise would be inefficiently intertwined with other essential solutions (Miranda et al., 2010).

INTELLIGENT AGENTS IN INTEROPERABILITY

There are a variety of methodologies and architectures through which it is possible to implement interoperability between HIS. These methodologies are based on common communication architectures and standards such as HL7. However, there are still some concerns about the distribution, fault tolerance, and communication standards. The multi-agent technology has been to stand out in the area of interoperability, including interoperability in healthcare, addressing the concerns mentioned above.

This technology is closely related to the basic concepts that define a distributed architecture. The agent-based computing has been vaunted for its ability to solve problems and/or as a new revolution in the development and analysis of software. The agent-based systems are not only a great promising technology, it is becoming as a new way of thinking, a conceptual paradigm for analysing problems and develop systems in order to solve problems related to the complexity, distribution and interactivity. Although there is no accepted definition for agent, it can be said that agents are understood as computational artefacts that exhibit certain properties such as (Jose Machado, Abelha, Novais, Neves, & Neves, 2010):

- **Autonomy -** the ability to act without direct intervention from peers, more specifically humans;
- **Reactivity -** capacity for integration into an environment, perceive through sensors and acting to certain stimuli;
- **Pro-activity -** ability to solve intelligent problems as planning their own activities in order to achieve their goals;
- **Social behaviour -** ability to interact with other agents and may even change their behaviour in response to this interaction. They can communicate through constructs and protocols of low or high level, as well as means of addressing and direct communication. Can cooperate to achieve a certain common goal, as well as their individual goals, i.e. must have the ability to negotiate with other agents.

In view of the above-described property agents can be defined to be autonomous, problem-solving computational entities capable of effective operation in dynamic and open environments. They are often deployed in environments in which they interact, and maybe cooperate with other agents that have possibly conflicting goals (Luck, McBurney, & Preist, 2003).

Agent-based software should be robust, scalable and secure. To achieve this, the architectures must allow compliant agents to discover each other, communicate and offer a service to one another is required. These architectures go beyond the capabilities of the typical distributed object oriented programming techniques and tools (Contreras, Germán, Chi, Sheremetov, & others, 2004).

Multi-agent systems for interoperability

Multi-agent systems (MAS) offer a new and often more appropriate way of development of complex systems, especially in open and dynamic environments. Some key features of the agent technology support these capabilities. The autonomy and pro-activeness features of an agent allow it to plan and perform tasks defined to accomplish the design objectives. The social abilities enable an agent to interact in MAS and cooperate or complete to fulfil its goals. The MAS can be considered as a rich and highly technology adaptable with a keen interest in the area of interoperability among HIS (Jose Machado et al., 2010).

To develop these systems is required specification standard methods, and it is believed that one of the characteristics for its high acceptability and recommendation is simplicity. In fact, the use of intelligent agents to simulate human decision-making in the medical field offers the potential for software suitable for the development and practical analysis and design methodologies that do not distinguish between agents and humans. These systems can provide a very skilful and effective to monitor the behaviour of its own officers, with a significant impact on the process of acquiring and validating knowledge, i.e. MAS make known the process of evolution of intelligent systems, and the replacement elements or task delegation generally performed by human beings.

The MAS is able to manage the entire life cycle of the agent, the availability of the modules of the HIS as a whole, keeping all agents freely distributed. New agents with the same characteristics and objectives can be created through the MAS depending on the needs of the system in which they are inserted. The structure of these agents and the MAS can be developed according to the services they provide and the logical functionality of systems that interact with them.

The agents in a healthcare facility configure applications or utilities that collect information in the organization. Once collected, this information can be provided directly to other entities, e.g. a doctor or to a server, stored in a file or sent by e-mail to someone for it to be treated at a later date (J Machado et al., 2010).

HL7 services in multi-agent system

The HL7 standard plays an essential role in the implementation of interoperability, in the development of exchange of medical information, the standardization of medical documents into eXtensible Markup Language (XML) structures and vocabulary specification for rugged use in messages and documents clinical allowing functional specifications for the EHR. Although healthcare standards like HL7 are completely distinct from agent communication standards, HL7 services can be also implemented under the agent paradigm.

These agents based on HL7 services can communicate with services that follow different paradigms and communicate with other agents that use both the HL7 as communication agents. Although the HL7 standard can be implemented using other architectures, agent-based solutions enjoy a wide interoperability capability, being able to be integrated with the more specific behaviours. These behaviours may become more effective if each time they use the machine-learning and other artificial intelligence (AI) techniques in order to adapt to the environment and be able to avoid errors and correct the flow of information and knowledge extraction within the institution.

As mentioned previously the standard HL7 not limit its use to any technology or architecture, however, aims to use regular communications between health systems oriented. There are obviously architectures and technologies that have become the most used, but the ones that stand out are those that are present by default in the information systems of specific equipment to perform various diagnostic methods.

However in the process of communication and exchange of information, we cannot only worry us with information systems, information exchange with the devices is increasingly important. These devices usually communicate through or standards of a loosely associated, i.e. directly with the information system (Medical imaging Information System, Cardiology Information System ...) or proprietary systems that may or may not consistent with other information systems. This type of equipment usually follows a client / server architecture in which the equipment is in most cases only a client. Taking all this into consideration it is understandable that there is considerable difficulty in establishing a system of uniformly understand and communicate fully with all services within a hospital. Even with the adoption of standards, specifically HL7, different flavourings usually require distinct handling of the messages and its events. To resolve this situation refers to the use of agents that enable you to create specific behaviours or agents that adapt to any situation by keeping all coupled systems (Miranda et al., 2012).

THE AGENCY FOR INTEGRATION, DIFFUSION AND ARCHIVE OF MEDICAL INFORMATION (AIDA)

Medical informatics is an area supported by two basic sciences, the Computer Science and the Health Sciences, which contributes to the improvement of quality in the provision of health services as it aims to better management of information resources and health. As mentioned in the previous sections, the interaction and communication based on specific protocols are fundamental to the successful implementation, execution and / or management of any HIS. Actually the HISs has to be described as a wide variety of distributed and heterogeneous systems that speak different languages, integrate medical equipment, which are customized by different companies, which in turn were developed by different people aimed at different goals. This leads us to consider a solution(s) for a particular problem, be part of a process of integration of different information sources, using different protocols through an Agency for Integration, Diffusion and Archive (AIDA) medical information, bringing health care methodologies to solve problems in medical education, computational models, tools and technologies (Duarte et al., 2010).

AIDA is a platform developed to allow the dissemination and integration of information generated in a healthcare environment. This platform includes many different integration capabilities, primarily used Service Oriented Architectures (SOA) and Multi-Agent Systems (MAS) to implement interoperability in a distributed, specific and in accordance with standard comprising all service providers within a health institution (Miranda et al., 2010).

This platform, designed to ensure interoperability between the HIS, it is characterized by electronic appliances provide intelligent workers, here understood as software agents, which have a pro-active behaviour and are responsible for tasks such as communication between different sub-systems, sending and receiving information (e.g., clinical or medical reports, images, data collections, prescriptions), management and economics of information and responding to requests, with the necessary resources to carry them out correctly and timely. The main objective is, as the name implies, integrate, disseminate and archive large data sets from various sources (i.e., departments, services, units, computers, medical equipment, etc.). However this platform also provides tools to implement and facilitate communication with humans through web-based services, i.e., the construction of AIDA follows the acceptance of simplicity, the conference meeting the common objectives and addressing responsibilities (Duarte et al., 2010; Peixoto et al., 2012).

AIDA’s Architecture

After a brief presentation of the AIDA described above is now possible to present the architecture of it. Figure 1 shows the same architecture where one can observe that AIDA is the central element in a healthcare environment ensures interoperability and communication between the following systems:

- The **Electronic Medical Record** (EHR), that it is a kind of repository of information on the study of the health of an individual subject of care, in a format that can be processed by computer, stored and transmitted from a secure and accessible by multiple authorized users;
- The **Administrative Information System** (AIS) that seeks to represent, manage and archive the administrative information during the episode. The episode is a collection of all the operations assigned to a patient from the start to the end of the treatment;
- The **Medical Information System** *(*MIS), which seeks to represent, manage and archive clinical information during the episode;
- The **Nursing Information System** (NIS), which seeks to represent and manage archive information on nursing practices during the episode;
- The **Information Systems** of all **Departments** and services (DIS), in particular Laboratories (Labs), **Radiology Information System** (RIS) and Medical Imaging (PACS - Picture Archive and Communication System), which handles images standard DICOM format.

Figure 1. AIDA Architecture.

The presented architecture was expected to support medical applications, has the form of a web of web systems intelligent information processing, EHR is your greatest subsystem, its functional roles and information flow among them are controlled with adjustable autonomy.

Health professionals gather information and its value is stored and distributed automatically to where it is needed. Every document created within a particular specialized service honouring certain rules, keeping closer different departments. The coding tools and ordering are very useful for connecting different data to a particular problem, as the encoded data are very easy to access these are recommended for the decision support through the intermediary of Artificial Intelligence (AI). The built-in electronic sorting EHR can be used not only for medical equipment or pharmacological prescriptions, but also for the acquisition of laboratory and study images that are out of service where they were purchased. Furthermore, it can allow the centralization of exam display an examination, thus allowing the results to different services share some of the same patient, reducing the cost of unnecessary tests and, above all, to improve the quality of service to be provided.

There are also different access permissions when dealing with medical data. Although they can only be viewed by authorized personnel starting from any terminal within the health unit to even the laptop or PDA personal access must be flexible in order to allow professionals to access when needed. In other words, access to medical information is so important in terms of privacy and in terms of significance for medical situations. The messaging system allows you to create, send and receive messages online, can be very useful for the treatment of data, images or even to exchange files (Peixoto et al., 2012).

AIDA as a Multi-Agent System

Considering the previous sections can be noted that the AIDA platform is thus a pure communication system Multi-agent (MAS), i.e., there is no external environment influence and the agents only communicate with each other via messages. However AIDA contains different types of agents:

- The **Proxy Agents** (PAs) that provides the bridges between users and the system in terms of questions that can be formulated explanations that may be necessary, decisions may have to be taken and / or visualization of the results. The system interfaces are based on web-related front-ends using Hypermedia pages that can be accessed through a standard Web bowser;
- The **Decision Agents** (DAs) provide mediation capacities, acting by accepting a task of PAs. They can break down tasks into sub-tasks, sending them to be processed by the CAs, later integrating the results (returned by CAs);
- The **Computing Agents** (CAs) that accept requests of DAs specific tasks, returning the results;

- The **Resource Agents** (RAs) who have all the knowledge needed to access a specific information resource;
- The **Interaction and Explanation Agents** (IEAs), which act on the basis of argumentative processes that are fed with data and / or knowledge from both the PA and the DAs. Note that the plans received by the DAs may be partial, in that mode only after the completion of a task a trace can be compiled and an application can be delivered to the APs and / or DAs (Jose Machado et al., 2010);

AIDA's Database

Over the years, organizations have increased the use of databases and today they are considered essential for everyday tasks (Godinho, 2011). Particularly in healthcare units, databases have a vital role, since they store very important information about the patients' clinical status, administrative information and other relevant information for the healthcare services. Therefore, it is crucial to ensure the safety of these databases. They must have the following characteristics (Bertino & Sandhu, 2005; Drake et al., 2005; A. Rodrigues, 2005):

- **Confidentiality -** the database must have mechanisms to prevent intruders, so that unauthorized persons cannot access and publicize the data stored (Bertino & Sandhu, 2005; Kim et al., 2010; A. Rodrigues, 2005);
- **Integrity -** the database must have mechanisms that prevent modification of data by unauthorized persons. Thus, it is possible to keep the information from the database incorruptible and inviolable (Bertino & Sandhu, 2005; Kim et al., 2010; A. Rodrigues, 2005);
- **Availability -** the databases must have mechanisms to access the required information in time. In addition, it should have mechanisms for fault prevention and tolerance, so that the system will thereby be able to continue operating despite the failure of any component not affecting the normal operation of the organization (Bertino & Sandhu, 2005; A. Rodrigues, 2005).

In healthcare units, it is very important for databases to be available twenty-four hours a day, seven days per week, because theirs information is vital for solving the patients' problems and for hospital management. For this reason, it is essential to ensure the integrity and permanent availability of data even in the presence of faults (Godinho, 2011).

To achieve these goals, it is used fault tolerance mechanisms based on the data or components redundancy. The main databases of CHP - AIDA and SONHO - are based on an Oracle Real Application Clusters (RAC) System. This mechanism is provided by Oracle for improving the availability and scalability of databases. A RAC system is composed by a shared database witch can be accessed through the server/computer that contains a database instance and an ASM (Automatic Storage Management) instance. In this way, it is possible access to the database across multiple servers (Ashdown & Kyte, 2011; Drake et al., 2005; Strohm, 2012).

In AIDA database, there are also another fault tolerance mechanisms: a data guard solution. This mechanism consists in one or more standby databases (replicas of the original database), which should be in different places. In this way, when the master database is unavailable the replica can be used without the need to interrupt operation on the system. It is essential that the master and the standby databases are synchronized and the access is read-only during the recovering (Godinho, 2011). The Figure 2 presents the complete architecture of AIDA database with these two mechanisms.

Figure 2. AIDA's Database Architecture with RAC and data guard solution systems.

DATABASE WORKLOAD AND FAULT FORECASTING IN THE AIDA

The fault tolerant system adapted to AIDA's database mentioned in the Section AIDA's Database ensures the availability, reliability and disaster recovery of data. However, these mechanisms do not allow the prediction or prevention of faults. In this context, it emerges the necessity of developing a fault forecasting system. To achieve this goal it is essential monitoring database performance to verify the normal workload and then adapt a forecasting model to the database context.

Monitoring database's performance

The use of monitoring systems by organizations has been growing not only because they are useful to diagnose faults but also because it can help ensure data security (Nair, 2008). Monitoring is not a simple process, and its complexity increases as it becomes necessary to monitor of various components and systems with complex architectures. However, thanks to the Oracle Systems it is possible take advantage of several tools to help in this process. The performance views are one of these tools that enable to consult useful information for monitoring. The content of these views are refreshed periodically (Chan, 2008; Rich, 2013).

There are several statistics that can be used to characterize the behaviour of the database. According to the objective of preventing faults related to the resource limitation have been selected to monitor the following statistics (Chan, 2008; Godinho, 2011; Ramos, 2007):

- **DB time -** is the time elapsing between the instant of placing of the query by the user to the reception of all results, this time should be the lowest possible. In Oracle systems, this time is a sum of total time (including CPU time, IO time, Wait time) spent on all requests from users. Therefore it is a good indicator of the workload of the system. Typically, this time increases with the number of simultaneous users or applications, but it also may increase due to other system problems (Dias, Ramacher, Shaft, Venkataramani, & Wood, 2005; Godinho, 2011).
- **Numbers of transactions -** transactions are indivisible sequence of operations that perform some work on the database. A greater number of transactions can indicate more work. In Oracle databases, the number of transactions can be obtained by adding up the values of statistics "user commits" and "user rollbacks" since each transaction always ends with a "commit" command and any undo operation as a "rollback" command (Godinho, 2011; Schumacher, 2003; Shallahamer, 2007).
- **Number of executions -** one transaction consists of set of operations in the database depending one the query. It is important to collect information about the number of operations because it may be the case that there are few transactions but many operations. In Oracle databases this information can be obtained by collecting, the "execute count" statistic (Shallahamer, 2007).
- **Calls ratio (RC) -** ratio between recursive calls and total calls. A recursive call occurs when a user request need one query SQL that needs another SQL query. The total of calls is the sum of recursive calls and user calls (when a user request can be resolved through a single SQL query). Ideally this ratio should be as low as possible, since the high number of recursive calls can indicate problems with the design of tables or an excessive amount of triggers running at the same time. This ratio can be calculated by the equation (Rich, 2013):

$$RC = \frac{recursive\ Calls}{(recursive\ Calls\ +\ user\ Calls)}$$

- **Number of current logons -** each logon, i.e., session is associated with a piece of memory, so many simultaneous sessions can cause problems. Note that the number of logons does not represent the number of users because each user may have multiple sessions. In Oracle systems, the number of sessions can be obtained by statistic "logons current" (Chan, 2008).
- **Processor utilization -** it is necessary to constantly monitor its utilization because it is one of the most important database components. Low values of processor utilization may indicate problems at the level of I/O. If the values are too high, it can compromise the functioning of the database. The percentage of utilization can be obtained thought a command of operating system (Chan, 2008).

- **Memory utilization -** the memory is a key component to the speed of the database systems. Depending on the data location the access speed change. If the data is in memory speed is greater. However, if the data is on disk the access velocity is lower. This statistic is also accessible through the operating system commands (Schumacher, 2003).
- **Size of redo file** – represents the amount of redo entries (Kbytes). The redo files are used to store information about changes made to the database. An increase in the size of these files, it indicates a higher number of operations and therefore a higher database load (Rich, 2013).
- **Buffer cache ratio (BC) -** this ratio shows the percentage of data that is in memory cache, rather than in the disk. Normally, the BC is very high so it is necessary to pay attention if BC decreases, this may indicate lack of memory problems. BC can be calculated:

$$BC = \frac{(1 - physical\ Reads)}{(consistent\ Gets + block\ Gets) \times 100}$$

- **Amount of I/O requests -** the I/O operations need a long time to process. A large number of these operations can indicate memory problems and frequent access to disc (Chan, 2008).
- **Amount of redo space requests -** Indicates the lack of space to write in the buffer. Some delays may occur because it is necessary to write some data to disk to release memory. This can happen due to a poorly sized buffer, or excess entries generated simultaneously.
- **Volume of network traffic -** the network that interconnects all the components of the database. Therefore, the network is very important for database performance. If a volume of network is increasing greatly, the database can be slow and compromise users' requests (Chan, 2008).

Modified Early Warning Score

In medicine there is already used a model, the Modified Early Warning Score (MEWS), for the prediction, in advance, of serious health problems. This model uses a decision table, like the Table 1, to evaluate the clinical status of the patient according the monitoring patients' vital signs values. The sum of all these values represents the clinical status of the patient. (Albino & Jacinto, 2009; Gardner-Thorpe, Love, Wrightson, Walsh, & Keeling, 2006; Subbe, Kruger, Rutherford, & Gemmel, 2001).

Table 1. MEWS Scores.

MEWS Score	3	2	1	0	1	2	3
Temperature (C)		< 35.0	35.1-36.0	36.1-38.0	38.1-38.5	> 38.6	
Heart rate (min^{-1})		< 40	41-50	51-100	101-110	111-130	> 131
Systolic BP (mmHg)	< 70	71-80	81-100	101-199		> 200	
Respiratory rate (min^{-1})		< 8		8-14	15-20	21-29	> 30
SPO_2	< 85	85-89	90-93	> 94			
Urine output (ml/kg/h)	Nil	< 0.5					
Neurological		New confusion		Alert	Reacting to voice	Reacting to pain	Unresponsive

Normally, if any of the parameters have a score equal to two, the patient must be in observation. In the case of the sum of scores being equal to four, or there being an increase of two values the patient requires urgent medical attention. In a more extreme situation, if a patient has a score higher than four, he is at risk of life (Devaney & Lead, 2011; Subbe et al., 2001).

Scores table

To evaluate the behaviour of the database it is essential to study its normal workload. So, after collect the values of the statistics mentioned in the previous subsection during a month, it was possible evaluate the state of the database based on percentiles and classifying the state through a decision table created (Table 2). All statistics collected about the database (mentioned in section monitoring database's performance) are evaluated individually through the scores table. Depending on the value of the deviation, abnormal situations are assigned granted scores such as is done in MEWS.

Table 2. Database Gravity Scores.

SCORE	0	1	2	3
Value	< p75	p75-p80	p80-p90	> p90
Gravity	Normal	Low Gravity	Grave	Critical

According to the scores two situations can happen: less serious situations wherein the sum of all parameters' score is equal or less than four and serious situations wherein the sum is more than four. The value four was elected because in MEWS the value four also means the limit between less and more serious situations. Furthermore, the system's administrators agreed that this should be the limit. They also agreed that this value maybe will not be permanent and it could be changed. In the first situation a visual warning will be issued on the dashboard responsible for monitoring the system and in the second warnings will be sent (via email) to the database administrator, allowing he to take speedy action to prevent the occurrence of a fault in the database.

New limits are calculated at the end of each day, based on new measurements that are periodically collected.

AIDA's database workload

The most critical period detected in the workload of the AIDA's database during a normal day in CHP was between 10:00 to 12:00. It was detected three peaks: DB time (6.9 seconds), percentage of processor utilization (32.63%) and number of sessions (941).

Verifying the following points it is possible to verify the average values of several statistics related to AIDA database:

- Transactions per second – 214;
- Percentage of processor utilization – 18;
- Percentage of the memory utilization – 98;
- DB time per second – 6;
- Number of sessions – 681;
- Number of I/O requests per second – 632;
- Number of operations per second – 742;
- Buffer cache ratio – 0.998;
- Number of redo size (KB/s) – 152;
- Recursive calls ratio – 0.14;
- Network traffic volume (bytes/s) – 686 135;
- Redo log space requests per second – 0.55.

As it is possible conclude that AIDA's database has a high utilization. The average of the number of sessions is 681 sessions. Furthermore, one can observe that are executed on average about 214 transactions per second, resulting these about 742 operations per second in the database which shows that this is a database with a very high workload.

The Figure 3 presents six graphs for the following metrics: number of sessions, percentage of memory, volume of network traffic, number of transactions, operations and requests for I/O per second. In all these graphs are four lines, the green corresponds to the 75th percentile, the yellow to the 80th percentile, the red to the 90th percentile and the blue is the value measured every minute. This excerpt was taken from one of the critical periods of the day, verifying that the blue line with some frequency exceeds the limits established by the percentiles indicating the presence of an abnormal situation.

Figure 3. Extract from the monitor dashboard of AIDA.

If only considered the last measurement shows that the number of sessions and the volume of network traffic are above the 90th percentile, the number of operations per second is above the 80th percentile, and the number of requests for I / O operations is between 75 and 80 percentile. The other metrics are in a normal situation, below the 75th percentile. In this case, the sum of the overall score would be 9, which would provide a warning email of abnormality. However, this situation do not cause database fault and for this reason it is necessary to update limits. Limits are update in the end of the day taking account of all measured values that do not cause fault, in this way the model improves its ability to represent reality.

It is important to note, that emails are sent only 15 to 15 minutes in order to be used mean values to compare, thus avoiding the impact of small variations during the interval.

AGENTS WORKLOAD AND FORECASTING AND DETECTION OF FAULTS IN THE AIDA

Besides monitoring and prevent faults of the database it is also important monitoring the behaviour of the agents individually as well as the machines wherein they execute their tasks. Before forecasting faults or quickly detects them in order to reduce downtime, it is essential monitoring the agents and machines' performance.

Monitoring agents and machine's performance

In order to collect information about the performance of the agents and machines it was used the Windows Management Instrumentation (WMI) technology. WMI is the Microsoft approach for Web-Based Enterprise Management (WBEM), which is an industry initiative to develop a standard technology for accessing management. WMI uses the Common Information Model (CIM) standard to represent managed components such as systems, applications, networks, devices or even files. CIM is a standard, unified, object-oriented framework for describing physical and logical objects in a managed environment. To provide a common framework, CIM defines a series of objects taking into account a basic set of classes, classifications and associations. WMI objects can be accessed from scripts running either on a local machine or, security permitting, across a network. Besides that, it offers a powerful set of services including the recuperation of information and the event notification system. Furthermore, its utilization is easy because WMI uses a query-based language named Windows Query Language (WQL), which is a subset of the standard SQL (Structured Query Language) (Boshier, 2000; Costa, Luiz, & others, 2010; Lavy & Meggitt, 2001).

To characterize the agents' performance, it is collected three metrics (Microssoft, 2013a, 2013b):

- **Percent processor time -** percentage of elapsed time that all of threads of the agent's process used the processor to execute instructions.
- **Working Set** – maximum number, in megabytes, in the working set of the agent's process at any point in time. The working set is the set of memory pages touched recently by the threads in the process.

- **I/O Data Kbytes per second** – rate at which the agent's process is issuing read and write input/output (I/O) operations. This property counts all I/O activity generated by the process, including file, network, and device I/O operations.

On other hand to analyse the machines' performance it is also collected information about RAM memory and CPU and further about the disk's free space. These three metrics are collected in available percentage, in other words the available percentage of CPU, RAM memory and disk's space. Being aware of these three parameters it is possible characterize the machines' performance as well as identifying situations that the machine be at a crash state (Microssoft, 2013c, 2013d; Mirossoft, 2013) .

Agents and machines' workload

During a month it was collected the workload of the AIDA's machines and agents. As the Figure 4 shows, among the five machines that execute AIDA's agents, the hsa-aida08 machine is the one that consumes more CPU (an average of 14.09%) and the hsa-aida01 is the one that consumes more memory RAM (an average of 42,38%). On the other hand, hsa-aida01 is the one that consumes less CPU (an average of 5.5%) and hsa-aida08 and hsa-aida04 are the ones that consume less memory RAM (an average of 14.23% and 12.93%, respectively). It was also possible to confirm that the CPU's consume was constant only varying from 5 to 10 percent in maximum. The consumption of memory RAM was very constant.

Figure 4. Extract from the monitor dashboard of AIDA's machines.

In the Figure 5, it is presented the activity of the agent 101 during a day, this agent is executed continuously in hsa-aida01. As it can be seen on the left side of the Figure 5, the average of RAM memory consumption is constant and it round the 400-450 Mbytes. On the right side of the Figure 5, it can be observed that the number of processes produced by agent 101 is about 35. These are the reasons for the high consumption of RAM in hsa-aida01. In the Figure 5 it also can be observed that the average of CPU consumption badly exceeds the 10% and the I/O operations were constant during this day excepting some operations at the end of the day.

Figure 5. Extract from the monitor dashboard of AIDA's agents. Activity of the agent 101 during a day (from 00:00 to 23:59) in hsa-aida01. Number of processes, average of CPU usage (%), RAM memory consumption (Mbytes) and I/O operations per second (Kbytes). On the right the number of processes and CPU consumption is highlighted.

The high number of agents that are executed in hsa-aida08 justifies the high consumption of CPU. In this machine are installed agents that are responsible for archives transfer, billing, requests processing and verifications. Besides the number of agents, most of these are often performed, which also justifies the elevated use of CPU in hsa-aida08.

The hsa-aida04 is the machine that has more resources available as it can be seen in the Figure 5. So, it may be concluded that when a new agent is created, it should be installed in this machine. Monitoring AIDA's machines, besides prevent faults of its agents, as it will be discussed in the next subsection, it allows the system administrators manage the resources of AIDA's machines in order to take advantage of them in the best way.

Forecasting and detection of faults

In this subsection it will be presented two applications. One that prevents faults in AIDA's machines (where agents are executed) and by inherence prevents agents' faults too. The other application quickly detects and informs the system administrator if an agent is not functional. Both of these applications use a database independent from AIDA's database, because if AIDA's database is down the monitoring system of these applications are not interrupted.

When a fault occurs in an agent it is very important detect quickly the fault in order to repair it in the shortest period of time possible, preventing bigger damages in the normal working flow of AIDA. Each agent registers its activity in a log file situated in the machine wherein it is executed, furthermore the errors that agents catch are registered in other log files, which contain only errors. Based on the time that agents take to refresh the log file with theirs newest activity, it is possible characterize the normal activity of a specific agent, in other words it is possible know how often an agent is executed. Of course that it is necessary a minimum period of time (about two weeks) to collect these intervals of time that characterize the agents' activity. With a set of data collected about the intervals of time that an agent is executed and using a score table based on percentiles (similar with the score table presented in the previous section) it is possible classify the state of agents' activity, assigning a score such as is done in MEWS.

Once the only variable used to calculate the score is the interval of time, the table for this situation has five states (from zero to four), moreover after doing tests it was assigned to this score table the intervals between the percentiles 85, 90, 95 and 97.5 instead of going from the percentile 75 until 90 such as the score table mentioned in the previous section. As the model used on database for fault forecasting, if the score obtained was less than four then a visual warning will be issued on the monitoring dashboard, else if the score was equal to four an email is sent to the system's administrator in order to he take speedy action to restore the normal working flow and prevent future damages. New limits are constantly calculated for each agent improving the application's efficacy. In relation to the errors recorded in the respective log file, this application detects when a new error appears and informs (by email) the administrator with the details of what happened. To finish, this application is endowed with persistency in relation to the database state. If the database is down, all SQL statements are recorded in a file and the administrator is warned. When the database returns back to normal all registers are inserted and the limits are refreshed. During the database's down time, scores do not stop of being calculated and abnormal situations are detected, however the limits are not refreshed and the limits used in the score table are the last ones calculated.

The application related to the monitoring of the machines also uses a score table to identify critical situations. This application prevents faults in the AIDA's machines and by inherence prevents agents' faults too. Initially, there was an attempt to create a score table based on percentiles as the tables previous presented, but it did not succeed. The application sent several warnings false positives per day. The computer performance limits for a good operation is an issue that varies a lot. Those limits depend of the objectives that the system administrator wants for a specific machine. For example the hsa-aida01 machine only has agents that are running continuously and they are responsible for archives transfer and provide web services. This behaviour provokes, as it is possible see in the previous section, a high consumption of RAM memory. In this case, the system administrator should lower the RAM limits in order to avoid be warned in regular situations. So, the score table was created with default fixed limits that also were discussed among the system's administrators for the available percentage of CPU, memory and disk's space and through a management page, the system administrator can change these limits for each metric either generally or specifically for one machine. The default score table for all machines, based on MEWS, it is presented in the Table 3.

Table 3. Default scores table for fault forecasting in the AIDA's machines.

Scores	0	1	2	3
Available CPU (%)	> 50	50-25	25-10	< 10
Available RAM memory (%)	> 15	15-10	10-5	< 5
Disk's Free Space (%)	> 15	15-10	10-5	< 5

Once again, if the sum of all parameters' score is more than four, serious situations are detected and a warning (email) is sent to the administrator. For example, if a machine has 12 % of CPU available, 6 of RAM memory and 14 of disk's free space, the score is five, this situation is considered critical and the administrator will be informed to take preventive actions.

AIDA'S SWOT ANALYSIS

Once the AIDA is a vital piece of the normal operation of the HIS wherein it is installed, it is very important ensure that it offers the best functionalities and that users are satisfied. This analysis is intended to gather information about AIDA, in order to improve it. The SWOT analysis can reveal what are the great strengths of AIDA as well as its weaknesses. Furthermore, the opportunities than can be taken advantage of are highlighted and the key threats to AIDA are alerted. Hence derives the acronym SWOT: strengths, weaknesses, opportunities and threats. Strengths represent the internal power that an organization owns to fight against the rivalry. Weaknesses represent aspects that reduce the quality of the product and/or of the service taking into account the customers' opinion and/or competitive environment. Opportunities are defined as a set of conditions suitable for achieving certain objectives at the right moment, and threats are any inappropriate event or force in the external environment that causes damage to the organization's strategy. When this analysis is complete it is possible use the strengths to develop new strategies; once weaknesses detected, these may be eliminated and some strategies may be reinforced; the opportunities should be explored; the threats should be countered. Strengths and weaknesses may be detected by an internal evaluation, on the other hand opportunities and threats by an external one. The organizational environment wherein the SWOT analysis performs is composed of a huge number of elements and complex relationships of cause-and-effect it is split in the internal and external environment. The first one can be controlled by the organization since it is very sensitive to the strategies implemented. There are internal factors such as management, culture at work, finance, research and development, staff, operational efficiency and capacity, technical frameworks and organizational structure. Nonetheless, external factors such as political, economic, cultural, social, technological and competitive ambient, define the external environment, which is not controlled by the organization and acts homogeneously in all organizations included in the same market and the same area. It may be concluded that opportunities and threats affect all organizations, however the probability of their impacts may be reduced by each organization (Dyson, 2004; Pereira et al., 2013).

In the following subsections are presented the items of AIDA's SWOT analysis in the CHP.

AIDA's strengths

- Power management of change in the system;
- Ability to personalize objects like interface;
- High availability and support full-time;
- High accessibility;
- Security;
- Technologically modern system (R. Rodrigues et al., 2012; Santos, Portela, & Vilas-Boas, 2011) ;
- Ease of maintenance;
- Ease of use (Pereira et al., 2012);
- Credibility of the management team;
- Immediate access to detailed clinical information;
- Reports customized to meet the needs requires;
- High computing power;
- Interoperability (Miranda et al., 2010);

- Ability to remotely access the system in a safe way;
- Failures prediction of databases (Silva et al., 2012);
- Fast detection of agents' abnormal activity;
- Failures prediction of machines wherein agents are executed.

AIDA's weaknesses

- System documentation non-existent;
- Graphical interface slightly confusing;
- Necessity of paper documentation in some services of the CHP;
- Insufficient education and training of health professionals;
- Computers are old and consequently slow.

Opportunities to AIDA

- Ability to integrate other applications;
- Ability to provide information via Internet;
- Ability to expand and sustain new services;
- Increasing importance of digital files;
- Government incentives;
- Extinction of paper use in the CHP;
- Modernization and organizational development;
- Projection of more efficient and usable interfaces;
- Developing better and more effective security protocols;
- Increasing expectation of citizens to obtain answers of clinical services faster and, at the same time, reliable;
- Use of mobile devices to access the system;
- Use of new technologies in order to enrich the system.

Threats to AIDA

- High degree of competition from other systems;
- Expansion of software companies for the health market;
- Competition/market pressure;
- Competition for scarce talented IT resources;
- Economic-financial crisis and subsequent financial constraints;
- Readiness to recover from disasters;
- Cyber attacks (hackers);
- System is based on Internet Explorer.

It may be concluded that AIDA in the CHP is a system of high relevance, endowed of many positive points such as interoperability, good usability, faults forecasting and high availability. On the other hand, a small number of weaknesses were detected such as the inexistent system documentation, in spite of this weakness be overcome by the full-time presence of technicians, who are always available to assist any healthcare professional.

The computerization of the entire clinical process in all services of the CHP is not an easy task. Nonetheless, all the efforts are being made for concretize this main goal.

Relatively to interface, the Portuguese legislation forces the healthcare units save all information about every patient, consequently when a professional accesses the clinical process of a specific patient, every clinical information about him has to be displayed, which can make the reading process a bit confusing.

The fact of the technology is constantly growing, the current Portugal's financial situation and the high cost of new technology acquisition makes difficult replace older computers.

It is very important to look at all opportunities that may improve the AIDA. For example, the increasing importance of digital files creates a good opportunity to extinct the use of paper in the CHP. All the other opportunities such as integrate new applications and services, improve security protocols and use mobile devices should be well exploited in order to fight against the competition.

Relatively to threats, the SWOT analysis shows a few threats that the administration entities should be aware. The biggest threat perhaps it is the competition from other systems, despite the economic and financial crisis represent a big threat as well.

Security is an issue that the administrators should be always aware in spite of AIDA provides a high level of security, it is very important ensure the security and confidentiality of its information and prevent cyber attacks. It is also very important ensure the availability of the system, it means that the system should have alternatives to disaster situations, if the system crashes, the CHP must not paralyze its activities.

It may be concluded that after this SWOT analysis a lot of valuable information was acquired about the AIDA installed in CHP. Now it is possible recognize the best AIDA's characteristics as well as few negative points that may be removed. Furthermore, the team that administrates AIDA knows what prospects should be exploited in the future and what dangers they should be aware.

CONCLUSION

This chapter demonstrates the importance and the impact that the interoperability causes in healthcare information systems. The usage of the HL7 standard embedded in a multi-agent system (endowed of autonomy, reactivity, pro-activity and social behaviour) is fundamental to improve the communication among heterogeneous systems, in other words to achieve the interoperability among the healthcare information systems.

The intelligent and dynamic framework AIDA is presented in this chapter. It constitutes a solution to accomplish the interoperability in healthcare units surpassing functional needs as well as financial and technical restrictions among clinical, medical and administrative systems.

The main core of AIDA platform is its database. The AIDA's database must guarantee its confidentiality and integrity as well as its availability, which are ensured by fault tolerance mechanisms as RAC and data guard solution systems.

In order to prevent fault in AIDA's database, a fault forecasting systems based on MEWS model was adapted to database context. Besides this system prevent database faults, it was possible studied the normal workload of AIDA's database. In the Centro Hospitalar do Porto, it was verified a high utilization and workload of AIDA's database (an average of 681 sessions, 214 transactions per second and 742 operations per second). It was also identified that the critical workload of AIDA is the period between 10:00 and 12:00.

A similar fault forecasting system for the machines wherein agents are executed was implemented. A detection of faults system was also implemented. It enables to detect quickly the agents' fault in order to repair it in the shortest period of time possible, preventing bigger damages in the normal working flow of AIDA. Furthermore, it was possible studied the machines and agents' workload for the purpose of allow the system administrators manage the resources of AIDA's machines and agents in order to take advantage of them in the best way.

The AIDA's SWOT analysis demonstrates that the system has a lot of strong points as well as fewer weak ones. Through the identification of the system's weaknesses, it enables the system's administrators to avoid them. This evaluation proved to be a powerful tool, which has provided useful information to improve the quality of AIDA.

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KEY TERMS & DEFINITIONS

Interoperability: Autonomous ability to interact and communicate.
AIDA: Platform developed to ensure interoperability between healthcare information systems.
Intelligent Agent: Autonomous programs that operate in an environment in order to achieve a goal.
HL7: Standard for interoperability in healthcare.
Multi Agent System: System with multiple agents working together in order to achieve a global goal.
Fault forecasting: prevention of failures through the monitoring of the performance of the object intended.
Database workload: database performance based on its main statistics.
SWOT analysis: picking and discussion of strengths, weaknesses, opportunities and threats with the purpose of know better and improve a system.