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Healthcare Interoperability through Intelligent Agent Technology

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Abstract

With technological advances, the amount of data and the information systems in healthcare units has been increasing exponentially. The accessibility and availability of patients' clinical information are a constant need. The Agency for Integration, Diffusion and Archive of Medical Information (AIDA) was developed to fulfill this need and it was implemented at the *Centro Hospitalar do Porto* (CHP), revealing a highly successful, ensuring interoperability among CHP healthcare information systems. This paper presents a new AIDA module, which aims to monitor the activity of its agents. It revealed its usefulness, providing to the user the functionalities and the necessary data for it to make a complete monitoring of the activities of each AIDA agent. It was still considered an efficient system, since it does not compromise the resources of the machine where it was implemented. In addition, this module increases AIDA functionality and efficiency.

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Keywords: Healthcare Information Systems; Interoperability; Multi-agent systems; Interoperability Standards; AIDA; Monitoring; Functionality.

1. Introduction

Nowadays the Information Technology (IT) has an important role in healthcare institutions, it influences their work, information and knowledge flow. The unity of each service delivered and the technology implemented require

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Healthcare Information Systems (HIS) particularly adapted. In this way, it arises the need to ensure the quality of information and efficient technical skills whenever specific information is changed [1].

The majority of healthcare institutions have been doing considerable investments to improve the integration and interoperability in their environments. The increasing of the HIS development relates to the universal and omnipresent concern with the improvement of services delivered within healthcare institutions and with the reducing the costs associated with these services through optimization of existing resources [1–3].

The changes and the improvements in healthcare and in the services associated have advanced gradually. For example, the paper-based documentation has been gradually abandoned and the computers and the new technologies have been included in the daily functioning of these institutions. Through the interoperability a HIS constitutes the main tool in this environment and it should be shared by all existing solutions in the several areas of healthcare institution. In other words, a HIS should be defined as an Information System (IS) that fits to the processing and exchange of data, information and knowledge in a healthcare environment. Specifically a HIS should make use of existing systems to collect, process, report and use the information and the knowledge that exist in a hospital environment. This information supports decisions and manages policies, healthcare programs, education, research and specially the medical practices in an institution [3,4]. A HIS aims to the management of patients' information and it also should enable the extraction of clinical/management indicators. These indicators allow professionals to make decisions based on information with quality and improve the program planning and, consequently, the provision of healthcare services.

Therefore, a HIS should connect horizontally any service and application that exists in a healthcare institution, requiring interoperation among these services and integration of what they contain [2]. There are already several methodologies and architectures whereby it is possible to implement interoperability among the HIS. These methodologies are based on common and standard communication architectures. The Multi-Agent System (MAS) technology has been standing out in interoperability area, including the healthcare interoperability.

To resolve this recurring need, University of Minho researchers together with the *Centro Hospitalar do Porto* (CHP), one of the largest hospitals in the north of Portugal, developed the Agency for Integration, Diffusion and Archive of Medical Information (AIDA) [5]. The AIDA is a platform that allows/facilitates the dissemination and integration of information generated in hospital environments. It incorporates various integration capabilities through technologies like Service Oriented Architectures (SOA) and MAS, which ensure the interoperability in a specific and distributed environment. It respects standards requested by services providers that constitutes a healthcare institution. AIDA is characterized by electronic applications that provide intelligent workers, intended as software agents that have a proactive comportment. They are responsible of tasks like the communication between different systems; the send and receipt of information (for example clinical or medical reports, images, collect of data, prescriptions); the management of information; and the responses to requests correctly and timely [6,7].

With the increase in the amount and complexity of the data generated in a healthcare institution, the number of agents created to ensure the interoperability has been increasing too. Thus, it emerges the need to create a system to control these agents. The new AIDA module presented in this paper has the purpose to assist the AIDA administrator to create new agents, to schedule their activities and especially to monitor their activities. In the sections below it will be presented this module, its functionalities and the result of its implementation in a real environment, the CHP. The document is organized in five sections. This first section makes a little introduction presenting the main problems to solve. The second section discusses the study area, interoperability and the best ways to ensure it in healthcare environments. The AIDA platform and the module to control the agents are presented in the third section and its implementation in the fourth section. Finally the conclusions and the future work are exposed in the last section.

2. Interoperability

To solve the problems of independence existing among the HIS, it is indispensable to implement mechanisms of communication and cooperation in these systems. Thus, the overall performance, the utility, the quality of the diagnostic and, mainly, the quality of healthcare delivery to the patient are improved as demonstrated in [8]. The concepts of integration and interoperation are in different conceptual levels and with distinct goals. Both are important for the cooperation and the flow of information, however they are based on distinct principles. In a simple way, the integration aims gather and acquire information from several systems for another system that requested this information, while the interoperation focuses its goal in the continuous communication and exchange of information among cooperative systems [5].

The interoperability concept is defined as the capability of a system or a product to work with other systems or products without any special user's effort. From another point of view, and in a more complete way, it can be defined as the capacity that an independent system has to exchange significant information and initiate actions belonging to other systems to work together to achieve a mutual benefit. The main goal of interoperability in healthcare area is to connect applications and data in order to be shared by the entire environment and distributed to health professionals when and where necessary. Nevertheless, to ensure the interoperability in a healthcare environment is a hard task specially due to the complexity and specificity of medical information and also due to socio-political and ethical problems [9].

The health data complexity gives to HISs integration difficulties and interoperability problems. A way to solve these problems is to use a common data model. However, the degree of integration of the HISs depends on the model flexibility. There has been an intensive effort to develop adapted and optimized standards in the healthcare area. Several models have arisen from these standards, however there are not much consensus on comparative evaluations. The Health Level seven (HL7) has been highlighted, being considered the more adaptable standard to healthcare interoperability. So the standards in healthcare are considered the main source to ensure the interoperability among the HIS. These include standards related with messages (HL7); terminologies (Systematized Nomenclature of Medicine - Clinical Terminology SNOMED-CT); clinical information and patients records (openEHR and HL7 Clinical Document Architecture CDA); and images (Digital Imaging and Communications in Medicine DICOM) [10,11].

Beyond the standards, generally it is used methodologies based on common communication architectures to ensure the interoperability among systems. One example of those methodologies is the MAS technology that is closely related to the fundamental concepts that defines a distributed architecture. These systems offer a new way to develop complex systems, especially in open and dynamic environments. The autonomy and pro-activity are the characteristics that allow to plan and to execute agent tasks in order to achieve the proposed goals. The social skills (communication capacity) enable the interaction and the cooperation of an agent inside a MAS. Thus, the MAS may be considered a rich and highly adaptable technology with a large interest in interoperability area.

Several agent-based systems have been developed and implemented in healthcare area. More specifically, tools have emerged, for instance, in the management of clinical data, decision support systems and systems for remote monitoring of the patient [12]. The recruitment in clinical trials with an agent-based system was tested by G. Tyson [13], he concludes that agent-based approach has several potentialities over the client-server approach. The enactment of clinical guidelines by a general framework based on a MAS and knowledge representation techniques was proposed by D. Isern [12].

However, many solutions have been emerging to bypass interoperability problems and to facilitate the flow of patient information in a healthcare organization. Most of these solutions are based on Java Agent DEvelopment Framework (JADE) technology that allows the agent creation and their communication in a MAS according with Foundation for Intelligent Physical Agents (FIPA) specifications [15–17].

3. AIDA

Techniques based on Artificial Intelligence have shown great potential when introduced into solutions applied in hospital settings. AIDA is an example in this issue, it corresponds to the central unit of interoperability in several large organizations like the CHP, the *Centro Hospitalar do Tâmega e Sousa*, the *Centro Hospitalar do Alto Ave* and the *Unidade Local de Saúde do Norte Alentejano*. This platform based on agent-oriented paradigm, has demonstrated a high adaptability, modularity and effectiveness through the use of a basic MAS that grows according the particular needs of each institution.

AIDA is a complex system composed by simple and specialized subsystems defined as intelligent agents responsible for tasks such as the communication between heterogeneous systems, the sending and receiving of information (e.g. clinical reports, images, a set of data, prescriptions, etc.), managing and archiving of information and responding to requests properly. Its main goal is, as the name implies, to integrate, to disseminate and to archive large sets of data from different sources (e.g. services, departments, units, computers and medical devices). It also provides tools to implement and to facilitate the interaction with the human beings [5,6,18].

Since the AIDA platform has taken a vital role in the normal functioning of the HISs in the institutions where it was implemented, it is very important to ensure that AIDA provides the best functionalities and its stakeholders (administrators, physicians, nurses, patients...) are satisfied with its performance.

Once the agents are the core element of the AIDA platform, a small abnormality on their executions may cause several troubles in a health care institution. One of these problems can directly or indirectly influence the treatment of patients. So the AIDA administrators need to know when a specific agent is executing its activities, how much time it takes to perform it and some other information. Thus, it emerged the need to create a module for the control of the AIDA agents to identify possible failures of agents, to determine their origin and to solve these failures.

3.1. AIDA Module for the Agents Monitoring

This new AIDA module was developed with the goal to integrate a community of agents and to ensure their execution in a heterogeneous environment. These integration objectives are to ensure that all agents communicate with each other properly and to create an interoperable environment.

Technically, this module has an architecture based on the client-server architecture where the server has the ability to communicate with many clients simultaneously (Fig. 1). To implement the communication model among agents we used the Agent Communication Language (ACL), a specification created by FIPA that provides a set of language primitives. The FIPA-ACL specification covers: the structure of an ACL message; the set of communicative acts (language performatives); and the set of communication protocols. In other words, it is a set of specifications that help to ensure the interoperability among agents and heterogeneous services. While the message and the protocols are specific and structured, the content of ACL messages is a free field and it is defined by the

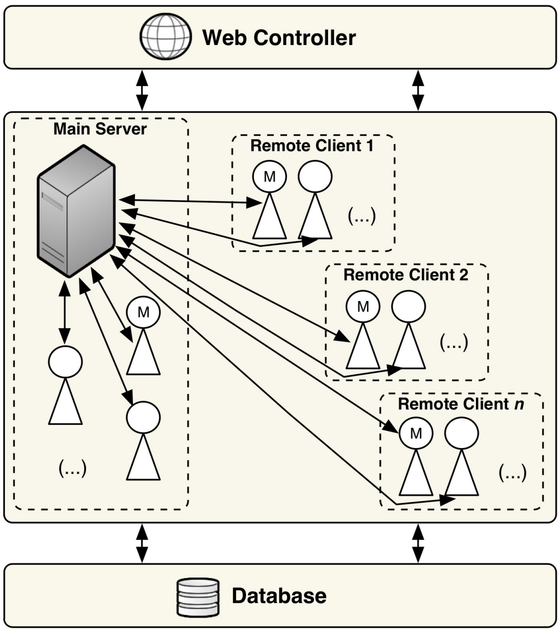

Fig. 1. Module structure and communications among the Database, Main Server, Remote Clients and Web Controller.

developer [19]. These messages are exchanged between agents by sockets that use a set of protocols TCP/IP. All information about the agents, their properties and the history of their activities are stored in a database. Finally to facilitate the interaction with the users, we developed a web user interface called web controller.

Using the technologies and methodologies described above, it was built the module that allows:

- Ensure a greater control over the agents that constitute the AIDA;
- Facilitate the user's work in the creation and registration of new agents locally or remotely;
- Allow the user to enable and to disable services at the healthcare unit, through the launch or stop of a particular agent;
- Facilitate the scheduling and rescheduling of the agents activity;
- Monitor dynamically and in real time the agent activity.

This module includes three components: the Main Server, the Remote Client and the Web Controller. The first two enable to the user to create new agents, ask for an agent execution and interrupt its activity. The main difference between these two components is that the first one, the Main Server, as the name implies, is the module server and it is able to do its actions remotely. It is the core component of the module and it is through it that the entire system is initialized. The third component is based on web and it offers to the user an interface that enables: to control the agents registered in the system; to access all information of each agent; to schedule all agents activities; and to monitor the agents actions.

For each agent the Web Controller provides a set of three pages. The first one, called Properties, besides to present the general properties about an agent, it also shows an overview of its activities: the date and time of the last execution of the agent; the duration of its activity; the total number of executions that the agent performed since its creation; the average duration of these activities; the total number of errors; and the most frequent error.

The scheduling page enables the user to view the scheduled activities for each agent. If the agent has not scheduled activities, it is possible to schedule a new activity. This scheduling may be done in a specific hour and day; daily with a specific hour; weekly in a specific hour and in a specific day of the week; monthly in a specific hour and in a specific day of the month; or periodically in a specific interval of seconds, minutes, hours or days.

The last page, called Monitoring, allows the user to visualize the agent activity details. More specifically, in this page there are two kinds of dynamic graphs: the agent activity duration and the total number of agent executions. They present a daily, weekly and monthly analysis when the user selects one day in the calendar. The daily analysis shows the average duration of the agent activities sorted by hour of the selected day and the number of activities performed by the agent per hour. Similarly, the weekly and monthly analyses show the graphs for all days of the week/month that the selected day is inserted.

4. Implementation

After some laboratory tests this module was implemented in a real environment, the CHP. During this implementation the machines resources were monitored by a monitoring and fault forecasting system [20]. This process is important to compare the machines workload before and after the module implementation. The results presented below refer to the period between 10 and 16 of September 2013.

4.1. Results

A set of AIDA agents was inserted in the module. The results of one of them will be presented due to being one of those who exercises increased workload. This agent was scheduled to perform its activity every 10 minutes. It is responsible to ensure the interoperability with the *Sistema de Apoio às Práticas de Enfermagem* (SAPE), an information system wherein it is registered the data resulting from nursing practices. Some time later the user may already have a vision about the activities that the agent did.

Apart from the data that the properties page provides, the Web Controller generates graphics such as that shown in Fig. 2. These graphs enable the user know in real time the average duration of the activities of the agent in each hour on September 11th and in each day of the corresponding week.

Analyzing in detail the Fig. 2 (Daily Monitoring), the user can verify that the agent took less time to carry out its activity in the period between the 7AM and 8AM, about 281 seconds. Through the identification of the peaks of the

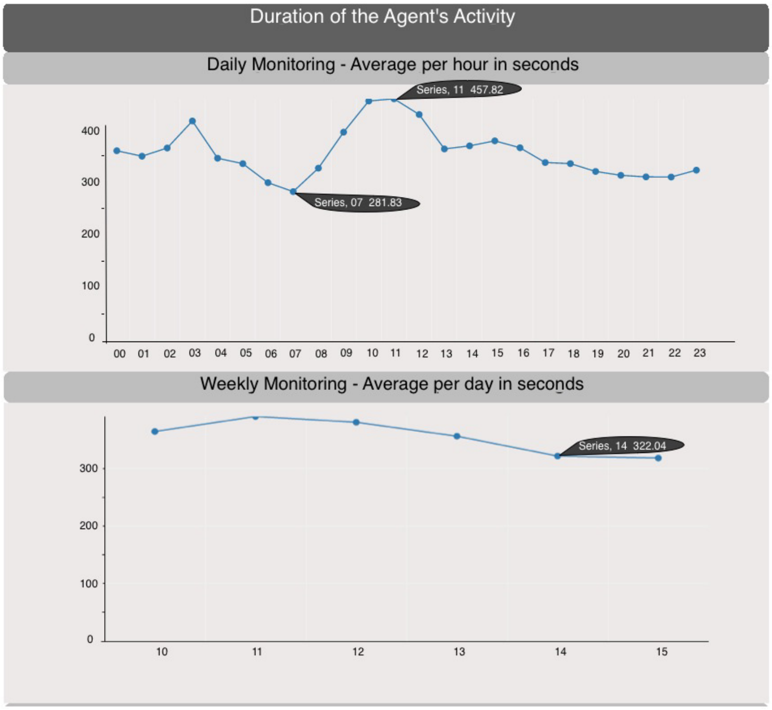

Fig. 2. Daily and weekly analysis of the agent activity average duration on the day 11 of September 2013 and the week where it is inserted (10-15).

agent activity duration, the user can compare it with the nursing service workflow. For example, the user can note that the affluence to SAPE is higher in the period between the 11AM and the 12PM, about 457 seconds. It is possible define the daily flow of the service with an abrupt growth of the agent activity duration from 8AM to 12PM and then a gradual decrease until 10PM. The user can also check the existence of a peak in the dawn at 3AM, this peak may be due to an emergency situation or maintenance actions that are generally performed during this period in the CHP.

Similarly in the Weekly Monitoring graph, the user visualizes which are the days that the agent takes more time to execute its activities and also observe the weekly flow. In this particular case, it can be noted that at the weekend the agent performs its activities much faster (322 seconds) and Wednesday is the day with the highest mean value (390 seconds).

With this type of graphic the user can make a better management of the whole platform, knowing what period and what days the agents have more functions, i.e. when its activity is more time consuming. Thus, the user can even decide what will be the best time to make routine changes, updates and other operations to improve overall module performance.

In order to evaluate the module performance, it was analyzed the data collected about the resources of the AIDA machines by the monitoring and fault forecasting system already mentioned [20]. It was analyzed the machines workload during the week 11-15 September (module already implemented) and during the week 21-25 August (before module implementation). More specifically, the free percentage of Central Processing Unit (CPU) and of Random Access Memory (RAM) of each machine was registered. The Fig. 3 presents the graphs about the free percentage of CPU in the two weeks mentioned above: the module implementation period (A) and a period before the implementation (B).

It is possible to verify that there was a slight increase in the percentage of free CPU in the implementation period. It is noted that in A the highest peak of the free CPU is about 99.35% whereas in B is 94.97%. Analyzing the presence of an abrupt depression in both graphs, it is possible to conclude that they occurred on the same day of the

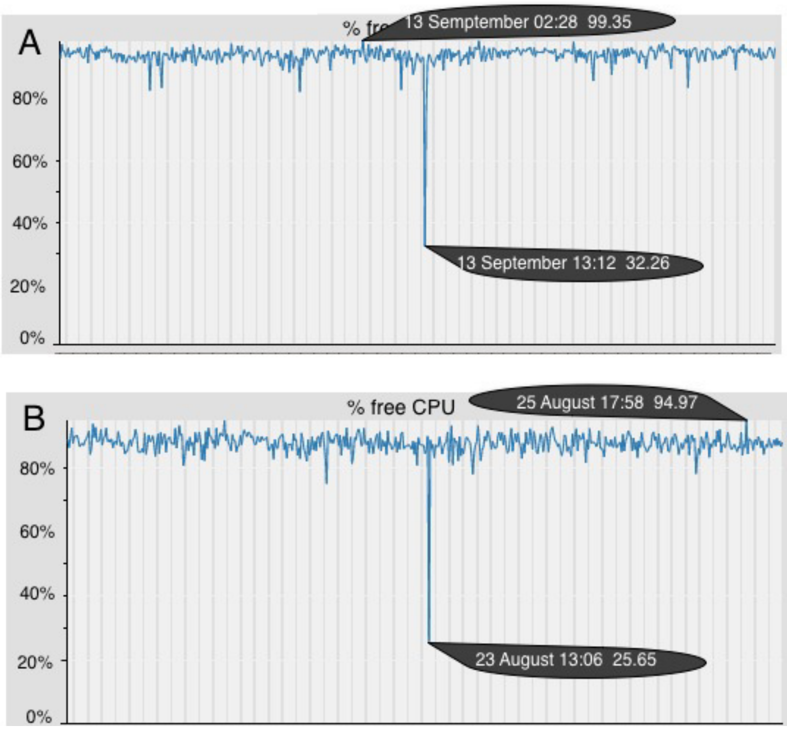

Fig. 3. Comparison of percentage of free CPU: (A) Period of module implementation (11 to 15 September); (B) Period preceding the implementation (21 to 25 August).

week at the same time, but as the highest values, in A the value of free percentage is greater than in B. With the percentage of free RAM the scenario was identical, the values were greater in the module implementation period than in the previous period. Getting this way proved that the module does not compromise the features of the machines where it was deployed.

5. Conclusions and Future Work

This project inserted in the interoperability thematic, an important issue nowadays. Over the years the interoperability has been highlighted as a requisite in most entities providing services. In healthcare and with the high importance of clinical information for medical practices, there is the need of information distribution and sharing among services and specialties.

The AIDA platform has been demonstrating a vital role in the interoperability implementation among HISs. So it is important to ensure the users' satisfaction regarding the AIDA performance. In this way, it was developed a new module to integrate in AIDA that allows to control and to manage a community of agents ensuring their survival in a heterogeneous environment.

The module was implemented in a real environment (CHP) where it was proven all their capabilities and functionalities. After the evaluation of the module implementation by the system presented in [20], it may be concluded that the module is an efficient system that does not compromise the machines workflow where it is implemented. It is important to note that this module is a generic system that can be applied to another multi-agent systems. Through it the user of the multi-agent system can create, subscribe and schedule their agents in a simple way. It may also be noted that its implementation in the AIDA platform comes to ensuring interoperability reliably with large scalability and growth capability.

As future work new graphs will be built in order to give to the users more information about the agents activities. The communication between this module and the monitoring and fault forecasting system [20] is being planned. The purpose of this communication is to enable the balancing of resources automatically through agents migration. Currently, when an administrator of AIDA creates a new agent, he selects a machine to host the agent. If this machine has load problems, the administrator has to move the agent manually to another machine. So, through an automatic balancing, whenever a machine reaches a certain threshold of CPU or RAM use, agents housed in this machine migrate to another machine with more features available.

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