ABSTRACT

Information technology has expanded enormously in the last decades affecting almost any field of activity. Healthcare industry couldn’t be out of this technical revolution. However, despite the huge potential demonstrated by informatics for the improvement of the healthcare industry, changes are going slowly. The implantation of the Electronic Health Record of a patient creates in the near future the possibility of collecting a complete bioprofile of a patient that conveniently analyzed can improve significantly the healthcare services, reducing cost and improving efficiency and safety of the patients. In this paper, after identifying the main requirements for a modern Medical Information System, we present MAMIS – a Multi-Agent Medical Information System. This system, inherently distributed, was designed with the goal of proving a solution for patient information search on a community of autonomous healthcare units and provide ubiquitous information access to physicians and healthcare professionals in a variety of situations.

KEY WORDS
Medical Information Systems, Distributed Electronic Health Record, Multi-Agent Systems

1. Introduction

Information technology has expanded enormously in the last two decades encompassing nearly every field of activity from finance and banking to universities. The healthcare industry, which is composed of hospitals, individual physicians practices, managed care providers, pharmaceutical companies, insurance companies and other entities, is no exception [1]. In fact, the first clinical computer applications were developed during the 1960s. Electronic Health Records (EHRs), on-line bibliographic databases such as MEDLINE, Bayesian systems or flowchart representations of clinical pathways were developed and started to be applied on real practice during this decade. Lately, during the 70s, the first expert systems were developed based on previous cognitive research. They aimed to capture the expertise of physicians and model complex medical diagnosis or treatment procedures [2].

Information Technologies (IT) have a tremendous potential for the increase on the safety, quality and efficiency of healthcare. Computer-assisted diagnosis, chronic care management, drugs prescription, patient records analysis and many other healthcare tasks can be significantly improved exploring the potential of the new information technologies. The easy and fast access to extensive patient data, the availability of decision support systems and other expert systems, the mobility and many other facilities provided by the new information technologies open a new world to the medical care industry. However, despite the potential demonstrated by these new technologies it is not an easy task. The traditional resistance to the change and the technical, political and ethical problems involved on the development of the new generation of Medical Information Systems (MIS) greatly retarded the diffusion of this kind of systems. Recent studies on the deployment of information systems in the health care sector show that limited resources are being applied on their development and application. Accordingly to [3] 92% of the surveyed health care providers have informational web sites but only 20% were participating on extranets or supply chain networks and only 15% were offering enterprise portals. Another study carried out on the United Kingdom also confirmed the reluctance of the health care industry on adopting the IT changes. However, the percentage of resources allocated to IT is continuously increasing and the revolution is certainly irreversible [4].

After a first generation of IT systems mainly dedicated to administrative tasks such as transaction processing and management information systems to support billing processes and simple patient records the trend is now changing and new systems for clinical proposes are improving patient care [5]. EHRs combined with Internet-based communication, may enable early detection of and rapid response to bioterrorism attacks, including the organization and execution of large-scale inoculation campaigns and ongoing monitoring, detection and treatment of complications arising from exposure to biochemical agents or immunizations [6; 7; 8]. It is important to note that the achievement of a paperless system is not a goal per se. The important objective is to have complete, easy to use, patient information that will enable various computer-aided decision support tools.

In the next paragraph we will analyze the requirements for a medical information system in order to justify the architecture proposed on the paragraph dedicated to the MAMIS architecture.
2. Main requirements of a MIS

A Medical Information System (MIS) can be a very complex application with important implications on the operation of almost all the areas on a healthcare unit. The main identified functionalities desirable for a MIS are (in random order):

- fast, easy and ubiquitous access to patient information
- support to diagnosis
- support to prescription
- physician-to-physician communication
- nursing communication and automated documentation
- physician/patient communication
- information confidentiality
- secure communications and information confidentiality
- easy and effective patient identification
- efficient patient management
- efficient alert system
- optimization of medical visits

We will now detail each of these functionalities.

**Fast, easy and ubiquitous access to extensive patient information:** the quality of the healthcare services depends greatly on the amount and quality of the information available about each patient. However, the access to the information must be easy and non time consuming. Otherwise healthcare professionals will not be motivated to the use of the underlying MIS and rapidly it will become obsolete. It means that information must be easily searchable and its visualization effective and fast. Human interface is also very important on any MIS because too much information and data may overwhelm or distract the end user [6].

The capability to display previous laboratory tests results can significantly reduce the number of redundant tests ordered saving money, minimizing laboratory and radiology equipment usage and preventing the patient from undergoing unnecessary tests [9, 10, 11]. It is known that digital information systems save a considerable amount of paper and time [12] but its adoption is usually not a smooth process. Healthcare professionals are usually busy people, with lots of concerns and not very available to the learning and test of new solutions. MIS must be attractive and offer evident advantages to the professionals in order to facilitate its adoption. Another important characteristic that any MIS must provide are ubiquitous access to patient information and support for offline information availability. While the former is useful for the access to the patients EHR from any www access point, without requiring any special software, the later is fundamental whenever the professional wants to move to isolated areas where www access is impossible for any reason.

An EHR must be, of course, as complete as possible. However, the information about a patient is rarely centralized on a single database. Usually it is distributed over a considerable number of healthcare units each one with its own database and EHR format. Mechanisms must be provided to collect the information from the different databases and present it to the healthcare professional in a transparent way with information converted to a uniform format, hiding syntactical and semantical incompatibilities. The creation of a unique database merging the information of all the units is usually not achievable due to ethical issues and to the natural greediness of healthcare institutions.

Of course that the access to the information about a patient involves a large number of ethical issues that are clearly outside the scope of this work.

**Support to diagnosis:** the availability of expert systems for diagnosis support can be an important advantage for the healthcare professional. Using diagnosis support systems patient data can be automatically evaluated and compared with similar cases proving the doctor with useful statistical information and diagnosis estimation or criticism. However, it must be stressed here that final decision is and will ever be human responsibility.

**Support to prescription:** the most common cause of adverse clinical events (about 19%) is medication error, and the commonest prescribing errors can be redressed by better information about medications or the patients receiving them [13]. There are, in fact, many benefits from the use of electronically assisted prescription (EAP) systems like the elimination of orthographic errors and non understandable calligraphy, the automatic drugs suitability checking and the inclusion on the prescription of educational information to teach the patient the adequate therapy.

Accordingly to Arnot Ogden’s chief information officer, Gregg Martin, “while there are other factors involved, error rates for omissions, transcriptions, wrong dose and wrong medication have decreased more than 50 percent over last two years” [12] in consequence of the installation of an EAP system.

**Physician-to-physician communication:** is another very important advantage of a MIS. Using adequate communication channels physicians can contact colleagues to clarify doubts, ask for advising or communicate interesting results. However, care must be taken when implementing these communication facilities. Any communication infrastructure where the number of useless messages becomes significant rapidly is ignored.

**Nursing communication and automated documentation:** communication between nurses and physicians is important on both directions. Physicians need to communicate nurse treatment directives and specific indicators to be observed. Nurses need to give feedback to physicians about treatment reactions, observations, etc. Electronic support for all this communication can save lots of paperwork and time. Automatic distribution of treatment directives and just in time scheduling can also improve the efficiency and the quality of the healthcare.

**Physician/patient communication:** provided that communication volume can be easily kept at acceptable levels, the establishment of an electronic link between patients and physicians can be extremely useful. Keeping in touch with its doctor the patient has a much stronger
feeling of safety and can provide important feedback about the therapy that is following. In consequence the doctor can adapt the prescription accordingly with the information provided by the patient avoiding unnecessary consultation acts. This mechanism has, however, two important drawbacks: patients tend to produce useless messages and the work undertaken by the healthcare professional analyzing and replying patient messages must be considered.

**Information confidentiality:** security is a central issue of any medical information system. All the information contained on a MIS and all the communications in this context must be safe. By safety we mean that only the right persons must be allowed to access or modify it. Safety is also linked to the possibility of harmful attacks destroying information or crashing the system making it unusable. Due to its importance and complexity the discussion of security measures is left outside of discussion at this stage of development once that already available commercial solutions can be adopted once the system is adopted for real life operation.

**Easy and efficient patient identification:** patient identification is usually done by name or some unique number such as the ID card number. However, when a patient is received in the urgency care unit without personal documents and unable to identify himself or during an emergency situation in consequence of an accident this is frequently not possible. However, even if a complete HER of each patient is potentially available, the absence of patient identification will annul any access attempt to this vital information. A reliable patient identification is therefore very important for any MIS. Biometric identification systems such as fingerprint recognition devices [14; 15] can be a good solution for this problem. Using this type of devices a patient can be reliably identified in a very short time by one of his fingers. In case the patient is unable to confirm his/her identity, the correct identification can be confirmed by the physician through the patient photo available on his electronic health record.

**Efficient patient management:** medical information systems can provide a very useful tool for management of the patient inside the clinical facilities. The scheduling of a patient analysis and tests can be done automatically improving coordination between hospital services, minimizing the waiting time of the patient and proving a faster reaction to the disease. Instead of following a predetermined sequence of tests the patient can receive a program for its tests with corresponding instructions at the same time that the schedule of the corresponding services is updated providing an efficient usage of the resources and maximizing the quality of service provided. Since computerized results can be accessed more easily by the provider at the time and place they are needed an increase on the both services efficiency and patient safety is expectable for quicker recognition and treatment of medical problems [16].

**Efficient alert system:** an efficient alert system can greatly improve the efficiency of the healthcare services. There are, in fact, a multitude of situations where an alert system can be useful. Alerts to clinicians (for example regarding changes on their patients conditions), to nurses and to patients are potentially useful to increase the quality and effectiveness of the medical care.

### 3. MAMIS – A Multi-Agent based MIS

The multi-agent paradigm has been successfully applied to a variety of scenarios where applications are inherently distributed [17; 18]. It is precisely what happens when several healthcare institutions are joined together by an information network establishing what is commonly called a virtual enterprise. A multi-agent system models the application as a collection of intelligent entities that interpret and react to incoming messages replying to it with adequate replies resultant of actions or computations performed. This abstraction is especially adequate to applications where different entities with particular interests collaborate with each other keeping their own individuality. In this type of applications information sharing is usually done on a very limited extent and many times only when a financial reward is received. Information hiding is one of the reasons that make centralized systems unviable. It is in fact difficult to imagine that two or more private clinics or hospitals join their patient databases and share their information and knowledge systems without a strong and hardly negotiated process. Moreover, there are a huge number of ethical and legal questions also involved on this information merging that must be considered. The multi-agent approach has the advantage of keeping each ones information completely private until there is a specific request for some portion of information or knowledge. This is the main reason for the adoption of the multi-agent paradigm for this medical information system proposal.

As it can be seen on Figure 1, where the general system’s architecture is depicted, the system can be composed by an unlimited number of healthcare units with identical structure linked by an information network such as the World Wide Web. The structure of Healthcare unit A is an example of a typical healthcare unit with its main components. It must be stressed here that all the architecture was motivated by the Biopattern Network of Excellence requirement of proving the doctor/scientist a complete patient phenotype and genotype. Therefore, it was considered an important advantage the possibility of accessing the information about a patient on different institutions keeping their individuality and autonomy. However, because internet connection is sometimes not available all the system is being designed to correctly operate and dynamically adapt to the resources available at each moment. The first prototype of MAMIS is currently being developed using JADE [19] as development platform and JAVA [20] as programming language. The databases are being developed using mySQL [21].
One of the central figures of this architecture is the doctor. On our model each doctor has a software agent that represents him in the system.

The Doctor agent (DA): this agent is mainly an information search agent that resides on the doctor’s default computer (desktop or portable computer) and is associated with a specific healthcare unit. The interaction with this agent usually begins by the identification of the patient under consideration by introducing his name or any other identification information. After identified the patient the doctor can instruct its agent to do either a local or a global search for information about this patient and specify each type of information he is interested on. Local information search means that only the database of healthcare unit where the doctor is associated is searched. Global search means that all the available databases will be searched. Despite the fact that the doctor agent typically resides on the doctor’s default computer, it is important that the information required by the doctor for its medical activity is accessible on a variety of places in order to allow its consultation even if the doctor moves inside or outside the clinic/hospital facilities, with internet connection or without it. MAMIS provides three different types of doctor’s access to their software agents: direct on the computer where the software agent is installed, trough the agent’s HTML interface that provides remote access using any web browser and by reincarnation of the doctor agent on a different computer for mobile temporary work on a different computer.

By specifying to its agent the characteristics of the desired information (identifying the patient and selecting the desired fields) the doctor can instruct his agent to launch on the net an “announcement” containing the corresponding query (on the actual version a mySQL query). The doctor can also specify if he wants the announcement to be local or global. Local announcements are divulged only inside the healthcare unit (or units) to whom the doctor is associated. Global announcements are sent to all the healthcare units accessible at the moment of the announcement launching.

The information search announcement is delivered to the agents that potentially have the adequate capacities (using the JADE services ontology mechanisms) that will analyze and react to it. Using a pure message passing architecture for the communication between the agents the reply to a information search message would be a reply message containing the desired information. However, in this application scenario it would be a poor solution because the volume of the information to be transmitted can be significantly higher requiring heavy message packing and unpacking computation. Therefore, an alternative solution was required and a database transaction solution in complement of the message passing architecture is proposed. On the adopted solution the agent who is asking for the information packs in the corresponding message the reference for its public database. The agents who receive the “information request message” look for the information on their private database. If the information is found, it is written on the database indicated by the sender. After concluded the writing of the information they just send a small reply message indicating that the information transaction is concluded. This architecture also facilitates the implementation of multi-database integration tools. Public databases must have an neutral format, that everyone can read and understand. Private databases can be of any format. Conversion between the two formats is responsibility of the owner of the databases. This model can be easily enriched with security protocols and information encryption that will guarantee the confidentiality of the
information transactions. However, this is a particular point where GRID [22] can provide a very useful solution. By proving to each agent a secure, distributed, fault tolerant database where the other agents can write whenever authorized and only the owner can read, GRID can provide the ideal communication channel for information transaction between the agents. The GRID database will only be introduced after concluded the first phase of development when also security solutions will be introduced.

Besides information search, MAMIS will offer doctors other possibilities. Using the peers conferencing facility, the doctor’s agent offers the possibility of sending messages to the potentially useful colleagues (trough their software agents) asking for the establishment of a communication channel were they can chat about technical problems and receive advises. This is very like the chat systems such as Microsoft Messenger but with extra functionalities. Contact calls will be automatically directed to other doctors agents registered with adequate capabilities with an importance level and a urgency degree assigned to each call in order to highlight the most important and urgent situations. This mechanism will offer physicians a useful tool to contact peers in order to get advice or collect opinions on difficult situations.

MAMIS permits physicians to easily and rapidly finding medical information about subjects of interest (see Medical Information Agent), provides assistance on drugs prescription (see Prescription Support Agent), gives automatic advises on diagnosis (see Diagnosis Agent) and offers an effective communication channel to nurses in order to change healthcare information with the nurses that assist patients (see Nurse Agent).

**Medical Information Agent (MIA):** this agent acts as an interface between the system and medical information repositories (such as the medical symposium). When a physician needs information about a subject, instructs his agent about the characteristics of the required information using a predefined information ontology. After defined the required information, the doctor agent launches in the system a “knowledge search” message that is automatically broadcasted to the MIAs. When the message is received the medical information agent searches for the required information on the repository and transfers the results to the database of the doctor agent that requires it. It is important to emphasize that this is a completely dynamic process. When a new “knowledge search” message is issued, the available agents at that moment will automatically receive the message and react adequately to it.

**Prescription Support Agent (PSA):** is an adviser agent that helps the physicians on their prescription activity. When a new prescription is completed by the physician, he can fire the prescription analysis process. This process begins with the broadcast of a message requesting the analysis of a prescription to all the prescription support agents available at that moment. The prescription support agents that are in conditions of analyzing the prescription answer back with a proposal that might include a “quality estimation” of their analysis (the quality of each analysis might depend on the particular disease, patient conditions, etc). After receiving all the answers, the doctor agent that issued the request for prescription analysis ranks the proposals and chooses one of the prescription support agents. Then, the prescription is sent to the selected PSA together with the patient identification that allows the support agent to have access to the patient information. This way the prescription support agent can analyze the full patient record and study possible patient incompatibilities or inadequacies to the prescribed drugs as well as incompatibilities with previously taken drugs.

**Diagnosis agent (DIA):** it is very similar to the prescription support agent. All the structure of a DIA is similar to a PSA except that the former is dedicated to the analysis of clinical situations were advise is required. In order to be able to do this job, the DIA is powered by an expert system that observes the patient electronic record and the information introduced by the physician in order to produce a diagnosis of the patient disease. Like in the PSA case the opinion of the DIA can be visualized by the physician and taken into consideration for the final diagnosis but it is, of course, just a recommendation. The final decision is, and will always be, physician responsibility.

**Nurse agent (NUA):** each nurse in the healthcare unit has a software representative in the system – its NUA. This way, each NUA can be configured accordingly to the specific characteristics of the nurse it represents. Using their NUA nurses can access information about patients, receive messages from physicians, send information about patients and treatment programs to physicians, etc.

**Database agent (DBA):** it is the interface agent between the healthcare unit database and the other agents. It receives information search and update messages from authorized agents and executes the respective database operations on the healthcare unit database. Each healthcare can have one or more databases each one represented by one DBA.

**Laboratory and radiology agent (LRA):** it represents the laboratory and radiology departments in the system (multiple instances of this agent can coexist simultaneously). Physicians can query this agent to learn about the estimated waiting time, recommend special procedures for specific patients and have access to tests results in a fast and straightforward way.

**Automatic drugs machine agent (ADA):** this agent interfaces the automatic drugs selling machines to the system. When a new prescription is defined it can be broadcasted by the physician or other authorized agent to the ADA agents. When a prescription is received the ADA agents build a proposal for the drugs delivery that can be complete or incomplete (if not all the drugs are available in the stock of its machine). Incomplete proposals will be automatically combined by the announcer agent in order to build composed proposals [23]. After combined, proposals are ranked according to some criteria (price, geographic distance or other criteria) and displayed to the user. This information can be used
for user selection of the most convenient drug machine. If the user selects one the proposals the drugs are automatically reserved for him on the corresponding machine for a limited period of time. If the period of reservation is not respected by the user the drugs are automatically freed. The installation of this type of machines on hospitals and other healthcare units can represent an important advantage for patients especially during the night, when the majority of the pharmacies are closed and drugs are difficult to obtain.

Telecare agent (TA): telemedicine and, in particular, the underlying telemedical information systems can contribute to solving important problems of modern healthcare systems: increasing costs, exploding information quantity, and quality assessment. The healthcare agent will provide data acquisition at the point of care to eliminate duplication of data storage and entry, insure that data is accurate and complete, guarantee confidentiality and security of patient records, and provide help to patients managing their own health. The adoption of adequate software agents to aid on the home healthcare program of patients the internment period can be reduced resulting on obvious financial saves and patient comfort without compromising the quality of treatment [13].

4. Conclusions

In this paper we identified the main requirements for a modern medical information system and presented MAMIS – a multi-agent based architecture for the implementation of a ubiquitous medical information network. The proposed architecture shown to be ready to fulfill the identified requirements and demonstrated potentialities to constitute a distributed network of healthcare units that keeping their identity cooperate between them sharing information about patients by demand. Despite the fact that implementation of the underlying system is yet in a primary stage the already achieved results are encouraging and a guarantee that a useful and convincing system will be achieve in the near future.

5. Acknowledgments

This work was partially supported by Biopattern Network of Excellence – Computational Intelligence for Biopattern Analysis in Support of eHealthcare – Information Society Technologies, Contract No 508803.

References:
[3] T. Wilson, “The focus is care, not the business: Web data and diagnostics, physician collaboration take precedence over supply chain” InternetWeek.