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A methodology based on *open*EHR archetypes and software agents for developing e-health applications reusing legacy systems

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ABSTRACT

Background and objective: In Pervasive Healthcare, novel information and communication technologies are applied to support the provision of health services anywhere, at anytime and to anyone. Since health systems may offer their health records in different electronic formats, the *open*EHR Foundation prescribes the use of archetypes for describing clinical knowledge in order to achieve semantic interoperability between these systems. Software agents have been applied to simulate human skills in some healthcare procedures. This paper presents a methodology, based on the use of *open*EHR archetypes and agent technology, which aims to overcome the weaknesses typically found in legacy healthcare systems, thereby adding value to the systems.
Methods: This methodology was applied in the design of an agent-based system, which was used in a realistic healthcare scenario in which a medical staff meeting to prepare a cardiac surgery has been supported. We conducted experiments with this system in a distributed environment composed by three cardiology clinics and a center of cardiac surgery, all located in the city of Marília (São Paulo, Brazil). We evaluated this system according to the Technology Acceptance Model.
Results: The case study confirmed the acceptance of our agent-based system by healthcare professionals and patients, who reacted positively with respect to the usefulness of this system in particular, and with respect to task delegation to software agents in general. The case study also showed that a software agent-based interface and a tools-based alternative must be provided to the end users, which should allow them to perform the tasks themselves or to delegate these tasks to other people.
Conclusions: A Pervasive Healthcare model requires efficient and secure information exchange between healthcare providers. The proposed methodology allows designers to build communication systems for the message exchange among heterogeneous healthcare systems, and to shift from systems that rely on informal communication of actors to a more automated and less error-prone agent-based system. Our methodology preserves significant investment of many years in the legacy systems and allows developers to extend them adding new features to these systems, by providing proactive assistance to the end-users and increasing the user mobility with an appropriate support.

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1. Introduction

In most countries, the conventional healthcare model will soon become inadequate, due to the increasing healthcare costs for the growing population of elderly people, the rapid increase in chronic disease, the growing demand for new treatments and technologies, and the decrease in the number of health professionals relative to the population increase [1]. Recently, the United States Census Bureau estimated that the expected number of inhabitants in the United States older than 65 will be approximately 70 million in 2030, twice that in 2000 [2]. In Ontario, the most populous province of Canada, healthcare is expected to represent 66% of government expenditure in 2017, and 100% in 2026 [3].

Currently, most healthcare organizations rely on legacy information systems, which are difficult to maintain and evolve since they are not flexible enough to incorporate the new requirements frequently demanded by the end-users [4]. Many legacy information systems have been designed to support end-users working in static organizations, and they typically do not profit from recent advances in Information and Communication Technologies (ICT) [5]. In addition, information exchange between these systems still requires users' intervention and telephonic conversations between these users, while the expenses for redesigning or replacing these systems are often huge mainly due to their poor structure and complexity [6].

In Pervasive Healthcare, ICT is applied to support the provision of health services anywhere, at anytime and to anyone [7]. In order to interoperate in Pervasive Healthcare environments, heterogeneous Electronic Health Record (EHR) systems require the use of communication standards [8,9]. *open*EHR [10] is a foundation dedicated to the research on interoperable EHR, and has defined an open architecture based on a two-level model that separates information from knowledge. *open*EHR prescribes the use of archetypes for describing clinical knowledge, in which an archetype is a structure employed by a domain expert to represent some specific knowledge within this domain.

Software agents [11] are entities that employ Artificial Intelligence techniques to choose the optimal set of actions to be performed in order to achieve the goals specified by their users. They can communicate with each other and with their users, and they have properties such as sociability, proactivity and autonomy, which allow them to support their users in their daily activities. The cooperation and coordination abilities of two or more agents can be combined through the use of well-defined communication rules for building a Multi-Agent System (MAS) to cope with complex tasks [12]. In healthcare, software agents can help healthcare professionals exchange healthcare information during their routine tasks [13,14].

This paper proposes a methodology that employs *open*EHR archetypes and software agents to cater for the interoperability between legacy healthcare systems. In this work, we explored the challenges of creating archetypes in the cardiology domain using the archetype methodology and tools to formalize the representation of clinical information within the EHR. Furthermore, we investigated the challenges of importing and integrating archetypes into the healthcare applications. We studied several healthcare environments and identified the following main requirements that make agent technology suitable to be used in these environments: deal with the distributed clinical information to be shared by the stakeholders; provide a fast and safe communication among healthcare professionals and patients; keep the autonomy of healthcare providers; and gather clinical information proactively from heterogeneous healthcare information systems. Our challenge has also been to keep the original legacy application running while moving to a pervasive healthcare model, making use of new technologies and skills.

As a case study, we designed a system using our methodology that supports the preparation of a cardiac surgery by reusing legacy Hospital Information Systems (HIS). The remainder of this paper is organized as follows: Section 2 introduces the organization and problems of the Cardiac Department of a hospital in the city of Marília (São Paulo, Brazil) that inspired our research; it provides some background on the *open*EHR model and archetypes; it discusses the software agents employed in this methodology; and it discusses some related work. Section 3 presents the proposed methodology; Section 4 describes the case study and discusses our evaluation results; and Section 5 gives some concluding remarks and topics for future work.

2. Background

2.1. *Initial situation*

Cardiac surgery is one of the best examples of teamwork in surgery, since it requires the full integration of individual efforts with maximum efficiency to make sure that each action plan is performed successfully [15]. Cardiac surgery is performed by a work group of highly trained staff, here named *Heart Team*, which consists of a cardiovascular surgeon, who leads the surgical team; an assistant surgeon, who follows the instructions of the cardiovascular surgeon; a cardiovascular anesthesiologist, who administers the drugs to keep patients asleep during surgery; a perfusionist, who operates the cardiopulmonary bypass machine; and cardiovascular nurses, who are specially trained to assist during the cardiac surgery.

The Center of Cardiac Surgery of Marília (CCCM) is the Cardiology Department of the Santa Casa Hospital that provides ongoing follow-up care for the cardiac surgery procedure in Marília and surrounding cities, and it has a clinical HIS, named CCCMSys, to keep track of the care provided to its patients. The scheduling of cardiac surgeries involves a procedure that consists of the following steps: (1) check the availability of resources in Santa Casa Hospital, such as blood bank, Intensive Care Unit (ICU) and surgical center operating room, since Santa Casa has one blood bank, eight ICU beds, and two operating rooms; (2) set a date for a meeting of the Heart Team to discuss the surgery, for which medical reports containing information on the patient's EHR need to be obtained in advance from the cardiology clinics in which the patient has been treated; and (3) notify the patient about the time slot when the surgery is expected to take place. Quite often, the actors involved in this procedure (and in other clinical activities) rely on informal offline communication (telephone or fax) to perform their tasks.