# A Novel Architecture for Message Exchange in Pervasive Healthcare based on the use of Intelligent Agents

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*Abstract*— **In Pervasive Healthcare, novel information and communication technologies are applied to support the provision of health services anywhere, at anytime, and to anyone. Ubiquitous Computing technologies allow efficient and safe information exchange amongst caregivers and their patients in communities, homes and hospitals. Since health systems may offer their health records in various electronic formats, the *open*EHR foundation has proposed a dual model to achieve semantic interoperability between such systems. Intelligent Agents is a technology that has been applied to simulate human skills in healthcare procedures. In this paper, we propose an architecture for the exchange of context-aware messages in Pervasive Healthcare environments. This architecture is based on technologies from Ubiquitous Computing and Intelligent Agents, and complies with the *open*EHR dual model**.

***Keywords— Pervasive Healthcare; Intelligent Agents; Ubiquitous Computing; openEHR; BDI architecture***

## I. Introduction

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

The current healthcare model is centered on highly specialized people, located in large hospitals and focusing on acute cases for treatment. It needs to change into a distributed model, in order to produce faster responses and to allow patients to better manage their own health. A distributed healthcare model that pervades the daily lives of the citizens is more suited to addressing these challenges, and characterizes *Pervasive Healthcare*. According to [3], the goal of Pervasive Healthcare is to enable the management of health and wellness by using information and communication technologies to make healthcare available anywhere, at any time, and to anyone. This includes support for self-management, self-monitoring, self-care, preventive efforts, cooperation between patient and healthcare institutions, and between home and hospital, consultation and remote monitoring.

Ubiquitous Computing [4] encompasses a group of technologies - such as, smartphones, tablets, sensors - that exploit the advances of wireless connectivity to allow information to move along with the user. In healthcare, these technologies are being mainly employed to build supporting infrastructures for Health Information Systems (HISs) in hospitals, and in the development of mobile applications that extend the functionality of healthcare applications formerly limited by traditional computing technologies. Ubiquitous Computing has enabled new healthcare models, such as Distributed Healthcare and Mobile Healthcare, and is expected to be extremely helpful in the implementation of the Pervasive Healthcare model. In addition, this model will only be acceptable for realistic scenarios if it supports efficient and secure information exchange amongst the caregivers and their patients.

The exchange of health information among heterogeneous Electronic Healthcare Record (EHR) systems in pervasive healthcare environments requires communication standards that enable interoperability between these systems. Although Health Level Seven (HL7)[1] is a widely used international standard for message exchange between heterogeneous HISs, it has some well-known limitations for representing clinical knowledge, such as its combined use of structured components and coded terms, which can result in inconsistent interpretations of clinical information [5]. *open*EHR[2] is a foundation dedicated to the research of interoperable EHRs. *open*EHR is defined as an open architecture based on two-level modeling that separates information from knowledge, thereby addressing some of the limitations of HL7. *open*EHR prescribes the use of archetypes in the description of clinical knowledge, where

[1] http://www.hl7.org

[2] http://www.openehr.org

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archetypes are structures that are used by domain experts to represent knowledge in their specific domains.

Intelligent agents are software entities that employ techniques from the area of Artificial Intelligence to choose the best set of actions to be performed in order to reach the goal or goals specified by their users. They can communicate with each other and with their users, and they have a set of properties, such as sociability, proactivity, and autonomy, which allow them to support these users in their daily activities. In the healthcare domain, intelligent agents could help caregivers exchange and use health information when caring for their patients.

This paper aims to demonstrate the feasibility of designing and implementing an architecture for message exchange to address realistic pervasive healthcare scenarios. The proposed architecture is based on Intelligent Agents and Ubiquitous Computing technologies, and complies with current healthcare standards. This paper particularly addresses the architectural and technical challenges of combining these technologies in order to achieve our goals.

The paper is further structured as follows. Section 2 discusses some related work and Section 3 addresses the main technologies applied in our work. Next, Section 4 introduces our proposed architecture while Section 5 describes a case study that demonstrates the suitability of the proposed architecture. Finally, Section 6 presents our concluding remarks and makes recommendations for future study.

## II. Related Work

Many applications for ubiquitous computing, healthcare standards and intelligent agents in healthcare have been reported in the literature.

In [6], the authors propose an extension to the traditional instant messaging paradigm by using the Extensible Messaging and Presence Protocol (XMPP) to exchange XML messages that contain contextual information. This work has some similarities with ours, in the sense that the authors employ agents to exchange messages. However, that work does not explore the use of healthcare standards and does not take into account the agents' intentionality.

In [7], an approach to provide interoperability between self-care systems using SOAP messages to transport the contents of a Personal Health Record (PHR). This work has some similarities with ours, in that it addresses the interoperability of heterogeneous information systems through the use of healthcare standards, but it also differs from ours in that it does not apply agent technology.

In [8], a multi-agent system is proposed to control the administration of medication to patients as well as to control the available stock of medicines. This work shares some similarities with ours, such as the use of a multi-agent system to control clinical tasks. However, the authors do not comply with healthcare standards for message exchange.

In [9], the authors describe a proposal for the representation and persistence of clinical data of patients using the *open*EHR dual model. This work is similar to ours in the use of the dual model of *open*EHR Foundation. However, the authors do not use Multi-Agent Systems (MAS) for message exchange based on information obtained from the EHR.

## III. The *open*EHR Dual Model

The *openEHR* architecture was developed based on the two-level modeling paradigm, as shown in Figure 1. At the first level, a common *Reference Model* (RM) was defined in terms of a predefined set of classes that model the structure of an electronic record; and on the second level, specific concepts were defined by restricting the RM classes in terms of so-called *archetypes*, expressed in the Archetype Definition Language (ADL) [10]. An archetype constitutes a formal model of a domain concept and is expected to be easily understandable by a domain expert. At the implementation level, archetypes can be translated into any language. In accordance with the two-level modeling, data from users are stored according to the RM, but should also comply with the concepts expressed by the archetypes. The archetypes are designed by the domain experts, and not by information technology professionals. This approach should facilitate the interpretation of the knowledge extracted from the messages exchanged by health systems in various applications.

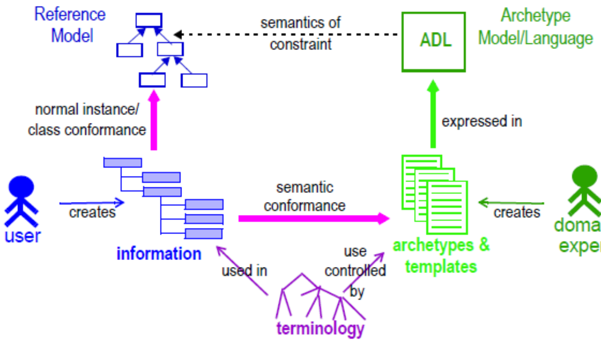
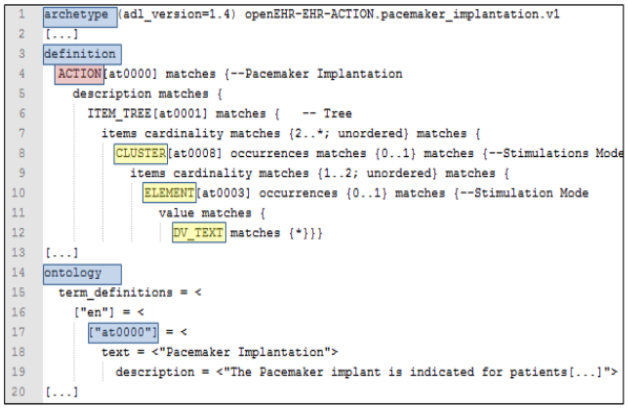


Fig. 1. *open*EHR dual model paradigm

In the *open*EHR RM, the COMPOSITION class refers to one or more instances of the SECTION class, each containing ENTRY objects. The ENTRY class represents the actual recording of clinical content during a patient Observation, Examination, Assessment, or Intervention. ENTRY is defined as an abstract type with four concrete subtypes: OBSERVATION, which can be used to represent clinical observations, such as blood pressure; EVALUATION, which can be used to represent assessments made after a clinical observation is completed, such as risk assessment, and finally INSTRUCTION and ACTION, which can typically be used to represent surgical procedures, medication, and other clinical interventions and actions taken. The ACTION subclass describes what was done and committed to the EHR as the result of an INSTRUCTION.

The Clinical Knowledge Manager (CKM) is the archetype repository of the *open*EHR Foundation. This repository contains a set of archetypes that represent clinical concepts and can be reused in various health applications. We have reused some available archetypes provided by CKM, such as *Device*, *Device Details* and *Clinical Synopsis*, and we have developed new archetypes to represent clinical concepts from the cardiology domain, such as *Pacemaker Implantation, Vascular Cardiac Surgery, Coronary Cardiac Surgery, Angioplasty Cardiac* and *Pacemaker Evaluation*.

The *open*EHR archetypes have been defined for general reuse, and they can accommodate any number of natural languages and terminologies. An archetype consists of three sections: header, definition and ontology. Figure 2 shows an extract of an ADL archetype for *Pacemaker Implantation* defined according to the *open*EHR standard. The *header* includes the name of the archetype (line 1). The *definition* section contains the structure and restrictions associated with the clinical concept defined by the archetype. *Pacemaker Implantation* specializes the ACTION class (line 4) of the RM. The CLUSTER part (line 8) refers to the 'stimulations mode' for pacemaker implantation, and consists of an ELEMENT with a value of type DV_TYPE. The *ontology* section (line 14-20) includes the terminological definitions. Here, the linguistic expression 'Pacemaker Implantation' is associated with the code 'at0000'.



```
1   archetype (adl_version=1.4) openEHR-EHR-ACTION.pacemaker_implantation.v1
2   [...]
3   definition
4     ACTION[at0000] matches {--Pacemaker Implantation
5       description matches {
6         ITEM_TREE[at0001] matches {   -- Tree
7           items cardinality matches {2..*; unordered} matches {
8             CLUSTER[at0008] occurrences matches {0..1} matches {--Stimulations Mode
9               items cardinality matches {1..2; unordered} matches {
10                ELEMENT[at0003] occurrences {0..1} matches {--Stimulation Mode
11                  value matches {
12                    DV_TEXT matches {*}}}
13  [...]
14  ontology
15    term_definitions = <
16      ["en"] = <
17        ["at0000"] = <
18          text = <"Pacemaker Implantation">
19            description = <"The Pacemaker implant is indicated for patients[...]">
20  [...]
```

Fig. 2. Archetype for the Pacemaker Implantation Concept

Healthcare professionals need to exchange knowledge, resources and information that pertains to the care of patients. In this work, we applied the *open*EHR approach based on the use of archetypes for generating messages to be exchanged between heterogeneous systems in pervasive healthcare environments. Archetypes were introduced in *open*EHR to improve the level of semantic interoperability in the message exchange between various HISs.

## IV. INTELLIGENT AGENTS

An agent is a computational entity with autonomous behavior that allows it to decide and perform its own actions. A software agent is an entity that functions continuously and autonomously in a particular environment that is often inhabited by other agents, and is capable of intervening in an environment, but without requiring constant human guidance or intervention. Agents can be classified according to their intelligence level. Agents with greater cognition abilities are classified as *cognitive* agents, whereas less cognitive agents are classified as *reactive* agents. Furthermore, if necessary, an agent is able to move in its environment by, for example, traveling between various hosts in a computer network.

Whenever the resolution of a goal requires the effort of two or more agents, we term this a Multi-Agent System (MAS). Although agents can inhabit a common environment, we must ensure the autonomy of each agent, which implies that each agent must have its own specific purposes and characteristics. The main objective of a MAS can be achieved through the cooperation and coordination abilities of its agents, combined with well-defined communication rules [11].

Agents in a MAS require the use a language that is understandable to them in order to exchange information effectively. The Agent Communication Language (ACL) proposed by the Foundation for Intelligent Physical Agents (FIPA) [12] is often used for this purpose, since it is a standard language for communication between agents. FIPA-ACL is based on the theory of speech acts and benefits from the formal definition of its *performative* library. A FIPA-ACL message is encapsulated as one of the message's attributes (*content*). To represent message content, FIPA established the language FIPA-SL (Semantic Language), which is based on first-order logic and aims to enable agents to express both properties and relations between objects from a specific domain.

Often it is necessary to incorporate *intentionality* in cognitive agents. The BDI architecture is based on intentionality, and considers *Beliefs*, *Desires* and *Intentions* as mental attitudes that generate human action [13]. The basic assumption of the BDI model is that *actions* are derived from a process termed *practical reasoning*, which consists of two steps to reach a state: *deliberation* and *reasoning*. The following example illustrates this process: after an intense semester of classes, a student has many options for leisure during his vacation. Among the alternatives, the student can travel, read, attend festivals, and so on. In the *deliberation process,* one of these alternatives is chosen. Suppose the student decides to *travel to some city*, in the *reasoning* step the student reaches a state in the process which results in a *plan*, enabling the student to arrive at his chosen destination. In this case, a *plan* would include purchasing tickets and boarding.

We applied the BDI model in the development of our architecture. This model allows the agents to operate in an environment according to what they believe, and to perform plans in order to satisfy their desires and intentions. We used JADEX [14] in our architecture, because it supports the formal description of cognitive agents that is based on the BDI model.

## V. ARCHITECTURE

The biggest challenge for our architecture is to support the mobility and collaboration among healthcare professionals when they perform clinical tasks. The main problems to be solved are related to information overload and the heterogeneity of the mobile devices used by such professionals. We use context-awareness, content adaptation, and the technology of intelligent agents to address the challenge and the problems mentioned above.

The architecture is expected to support use cases with message exchange services that are more complex than the simple communication between two specific end-users. These use cases require the participation of third-parties in decision-making, which are the *agents* that interact with end-users by exchanging messages based on the *open*EHR archetypes.

Figure 3 gives an overview of our architecture, which was developed according to the MVC pattern (Model-View-Controller) [15] that separates the business logic from the presentation logic, thereby increasing flexibility and reuse. In the MVC pattern, *Model* corresponds to the classes of the application domain, *View* depicts the model in an appropriate form to the end-user, and *Controller* receives the input and initiates the response to the end-user by invoking *Model* objects.

In our architecture, the *view* package contains the *mobileUI* package, which copes with the mobile end-user interactions with other components of the architecture, and the *webUI* package, which displays information to the end-users. The *controller* package contains the *CAManager* package, which manages the exchange of context-aware messages, the *handler* package, which processes the inputs and outputs and acts as a wrapper to a web service, and the *helper* package, which adapts the data model to the *view*. The *model* package represents the domain models, and contains the *ontology* package, which represents the domain knowledge, the *agent* package, which issues requests and notifications within the architecture, and the *dto* and *dao* packages, which represent the data transfer object and data access object design patterns, respectively. The architecture has also an *external* package with some additional auxiliary packages.

We defined a *CAManager* package*,* which includes a *contextManager* package to processes the dynamic context information (e.g., end-user's location) and other context information (e.g., identity, user roles) that is obtained from various contextual sources, *contextManager* interacts with the *adapter* package to handle content adaptation of the message containing health information, in order to address some the specific characteristics of the end-user's device. If adaptation is necessary, *contextManager* asks the *view* package to adapt the graphical interface to the particular device.

When the system interoperates with other HIS, *CAManager* and *handler* exchange messages that possibly contain extracts of an EHR. Such messages are represented in accordance with the specification of *open*EHR archetypes, in order to guarantee the interoperability with other HISs. The *handler* package also supports both synchronous and asynchronous communication between architecture agents and HISs. It requests the appropriate content from a legacy HIS, and checks if this content has messages related to the end-user.

The architecture includes *static* agents, which provide the necessary resources to the *mobile* agents, which in turn move through the architecture environment in order to achieve their goals, and communicate with other agents over an asynchronous communication channel.

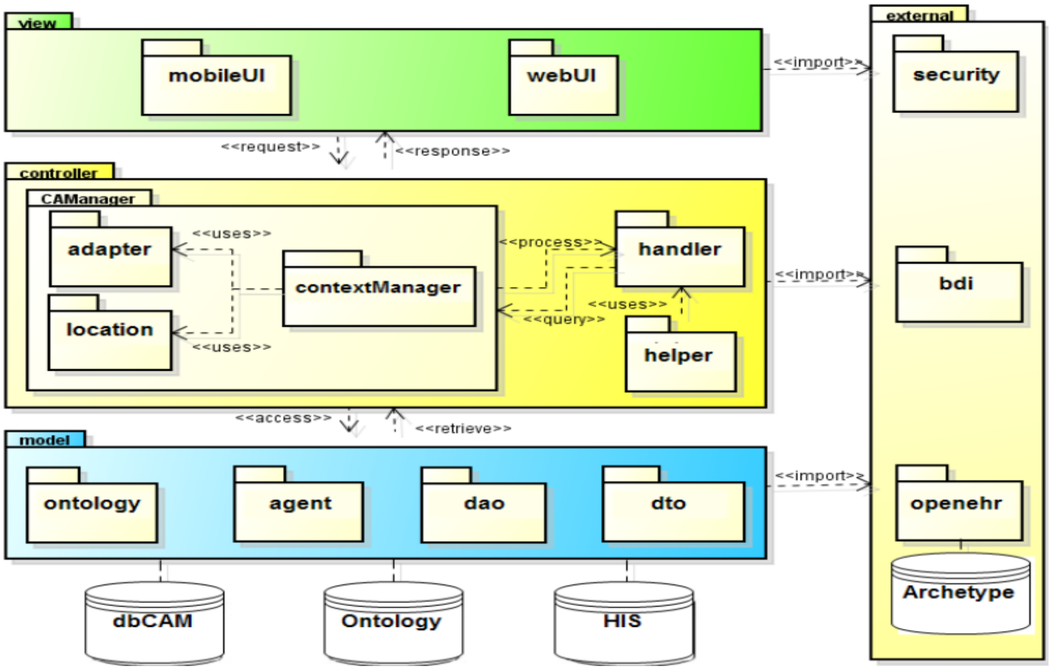


Fig. 3. Architecture

### A. Package 'Agent'

Figure 4 shows part of the components diagram and their dependencies within *agent* package. The agents were modeled using the *i** framework[3], which prescribes an agent-oriented approach centered on the intentional characteristics of agents. Agents who are endowed with *intentionality* are assigned with the *cognitive* stereotype, while agents that only display reactive behavior are assigned with the *reactive* stereotype.

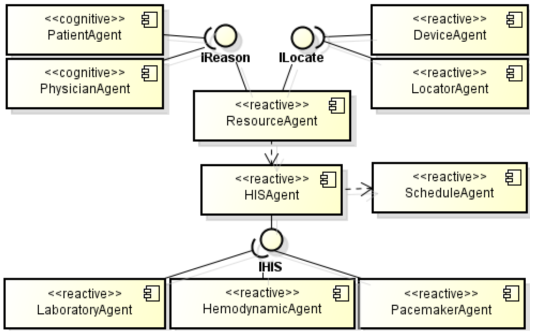


Fig. 4. Component Package 'Agent'

*HISAgent* is a component that corresponds to a static agent since it does not have the ability to migrate between various hosts. This agent analyzes various EHRs and has the ability to retrieve information from the EHR by extracting *open*EHR archetypes that have been requested by a *ResourceAgent* agent. The main task of the *HISAgent* is to ensure interoperability between various HISs through the exchange of messages between agents. The messages exchanged between the agents carry portions of an EHR, based on constraints imposed by the archetype, and such statements are structured according to the *open*EHR reference model. Figure 4 shows the *IHIS* interface provided by the *HISAgent* component and required by *PacemakerAgent*, *LaboratoryAgent*, and *HemodynamicAgent* components. These components define models for information retrieval from an EHR.

*ResourceAgent* is a static agent that runs on a remote server and is responsible for mediating access to resources related to *HISAgent*. This agent is *static* because it does not have the ability to migrate between various hosts. Component *ResourceAgent* provides the interface *IReason* to *PatientAgent* and *PhysicianAgent* components, which are the main agents that communicate with *ResourceAgent* for the purpose of obtaining information related to the EHR.

*PhysicianAgent* is a mobile agent that is endowed with *intentionality*. This agent is used by the physicians responsible for the patient's healthcare. This agent helps the medical staff monitor the tasks performed during a workday, and obtain information about patients and the availability of resources but without requiring the intervention of caregivers. Information about bedridden patients is obtained by the agent *ResourceAgent*. Initially, any member of the medical staff can use his or her mobile devices to trigger the *PhysicianAgent* that is responsible for achieving the goal determined in accordance with the plans, allowing the medical staff to deal with any emergency situations. *PhysicianAgents* are endowed with mobility and can be dispatched by the network in order to achieve their goals. When a *PhysicianAgent* migrates to another container, it keeps its *intentionality* according to its beliefs, so that it can achieve its goals. After achieving its goals, a *PhysicianAgent* returns to its origin (the machine from it was launched) bringing a message consisting of a string value, or a serialized Java object containing an extract of an EHR related to an *open*EHR archetype, or an *Ontology* object containing the description of the concepts used by the agents (i.e., in FIPA-SL).

*PatientAgent* is a component that corresponds to a static agent. This is an intelligent agent, since it has beliefs, desires and intentions and is capable of applying plans to pursue its intentions in the environment where it resides. The *PatientAgent* is responsible for the continuous monitoring of the evolution of the patient, and can send and receive messages from *PhysicianAgent*.

*DeviceAgent* and *LocatorAgent* are components responsible for determining the patients' and caregivers' locations. Bluetooth Access Points (BAPs) has been applied to handle location, namely the capability of discovering devices that are connected. BAPs are co-located with points of interest in the hospitals and clinics, in order to allow both people and devices to be located. Based on the location agents, *PhysicianAgents* can move through the platform in pursuit of their goals. Figure 5 shows an example of an ontology used for device location, enabling *DeviceAgent* and *LocatorAgent* agents to identify the owner of a given device. The various types of ontology schemes can be identified by the following stereotypes:

- *Concept*: denotes concepts of the ontology, such as, *"Device"* and *"Person"*;
- *Predicate*: denotes expressions that relate concepts to one another and can be evaluated as true or false. *Predicates* and *actions* are exchanged in the messages instead of *concepts*. Figure 5 shows the predicate *"owns"* indicating that a device has a given owner;
- *AgentAction*: denote *actions* that can be performed by an agent. For example, the action *"Locate"* indicates that an agent must locate the owner of a device.

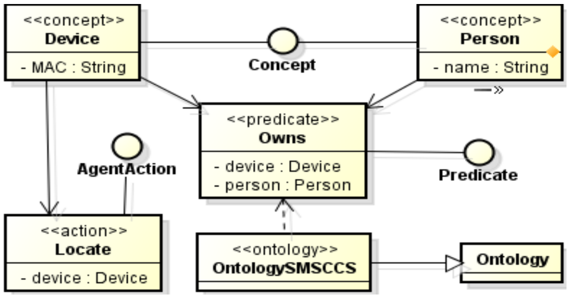
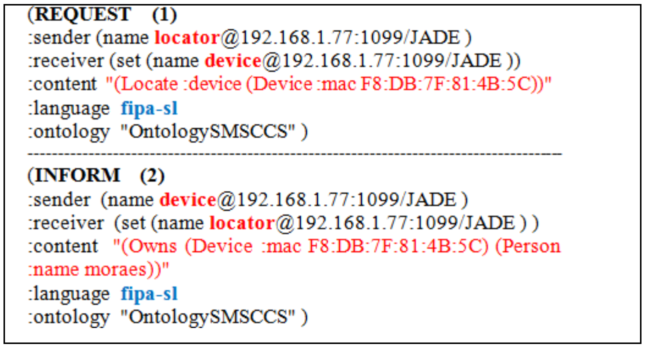


Fig. 5. Ontology for Device Location

[1] [3] http://www.cs.toronto.edu/km/istar/.

Agents need to communicate in order to achieve their goals effectively. Communication extends the agents' perception, by allowing them to benefit from the information and expertise of other agents. The *DeviceAgent* and *LocatorAgent* agents communicate by exchanging messages written a language that represents the semantics of the message content within the specified domain. Therefore, the *DeviceAgent* and *LocatorAgent* agents are able to understand the messages they exchange because they have the necessary domain knowledge (ontology) and the language they use has well-defined semantics.

Figure 6 shows two FIPA-ACL messages indicated by performative REQUEST and INFORM. In Figure 6 (1), an agent identified as *locator* has sent a request message to an agent *device*. The message is written in FIPA-SL and its content is related to *OntologySMSCCS.* The message indicates that the MAC address F8:DB:7F:81:4B:5C of a device was located by the access point. In Figure 6 (2), the *device* agent has sent an informative message to the *locator* agent. The message indicates that the *owner* of the device with MAC address F8:DB:7F:81:4B:5C is the person called *moraes*.



```
(REQUEST   (1)
:sender (name locator@192.168.1.77:1099/JADE )
:receiver (set (name device@192.168.1.77:1099/JADE ))
:content "(Locate :device (Device :mac F8:DB:7F:81:4B:5C))"
:language  fipa-sl
:ontology  "OntologySMSCCS" )
-----------------------------------------------------------------------------
(INFORM   (2)
:sender  (name device@192.168.1.77:1099/JADE )
:receiver  (set (name locator@192.168.1.77:1099/JADE ) )
:content  "(Owns (Device :mac F8:DB:7F:81:4B:5C) (Person
:name moraes))"
:language  fipa-sl
:ontology  "OntologySMSCCS" )
```

Fig. 6. ACL Message using Ontology

Each agent in the architecture is endowed with specialized capabilities and goals in order to perform tasks for the benefit of pervasive healthcare. The architecture allows the caregivers to detect abnormalities in their patients, check the availability of resources within the healthcare environment and obtain information about patients. Caregivers and patients may use any device, anywhere and at anytime.

## VI. Case Study

We have conducted a case study involving three cardiology clinics, and also the Cardiology Department of the Hospital Santa Casa, in the city of Marília (São Paulo, Brazil), using a usage scenario. IT professionals, under the guidance and assistance of professional medical experts, described the usage scenario. This scenario is discussed in the sequel, namely medical staff meeting as preparation for a cardiac surgical procedure.

Cardiac surgery is one of the best examples of the importance of teamwork in the surgical area. Due to the complexity of the resources involved, cardiac surgery requires the full integration of individual efforts with maximum efficiency to make sure that the surgical action plan is performed successfully.

Cardiac surgery is performed by a work group of highly trained staff, comprising:

- 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 cardiac surgery.

In this scenario, we show that out architecture allows the daily tasks of human agents to be delegated to software agents.

Figure 7 shows the class diagram instantiated from the components of the architecture, in which the class *Caregiver* represents all the stakeholders involved in cardiac surgery.

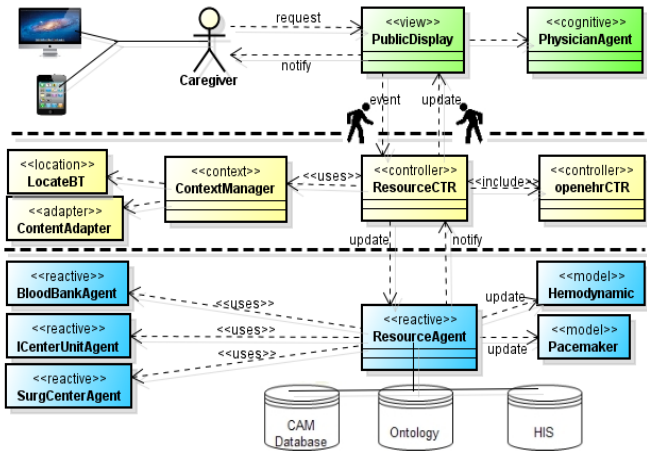


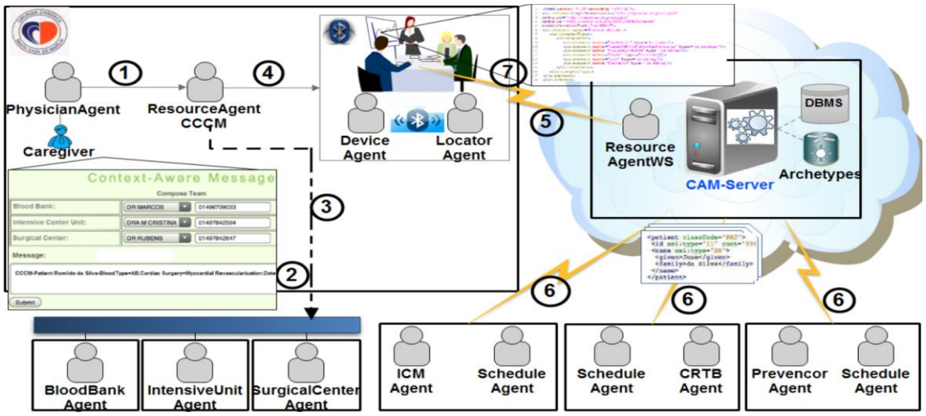
Fig. 7. Class Diagram (instantiated)

The following rules are involved in this usage scenario:

- Dr. Prince is a cardiac surgeon and Dr. Said is an assisting cardiac surgeon, both working at the Center Cardiology CCCM-Marília/SP;
- Dr. Cavalari is an anesthesiologist at the Santa Casa Hospital;
- Dr. Marden and Dr. Peter are physicians working in the Department of Hemodynamics in Marília;
- Eliene is a nurse and Aline is the perfusionist;
- This team works together to perform cardiac surgery on the patient, Mr. Silva.

The notifications necessary to perform cardiac surgery are exchanged in two phases. Figure 8 shows the interactions between the instantiated agents:

1) *PhysicianAgent* requests the required resources to perform the surgery;
2) *ResourceAgentCCCM* analyzes the conditions for performing the surgery;



Context-Aware Message

Compose Team

Blood Bank: DR MARCOS 01496709033

Intensive Center Unit: DRA M CRISTINA 01497842594

Surgical Center: DR RUBENS 01497842647

Message:

CCCM-Patient Romildo da Silva-BloodType=AB;Cardiac Surgery=Myocardial Revascularization;Date

Submit

```
<patient classCode="PAT">
 <id xsi:type="II" root="995
 <name xsi:type="EN">
  <given>Jose</given>
  <family>da Silva</family>
 </name>
</patient>
```

Fig. 8. Interaction Between the Agents

3) *ResourceAgentCCCM* checks the availability of the blood type at the Blood Bank (*BloodBank-Agent*), an Intensive Care Unit bed (*IntensiveUnit-Agent*), and a Surgical Center room (*Surgical-CenterAgent*);

4) Once these resources are available, *Resource-AgentCCCM* notifies each staff member to set a date for the meeting, by sending a message to their mobile devices. In the meeting room, which is context-aware, the staff members are located by the *DeviceAgent* and *LocatorAgent*. In the first action of this meeting, the surgeon registers the patient's name for a team discussion;

5) *ResourceAgentCCCM* requests all the information related to the patient's EHR through *ResourceAgentWS*;

6) *ResourceAgentWS* receives the messages from the cardiology clinics according to the contextual information, and serializes the extract of the EHR containing the patient's data based on the constraints imposed by the *open*EHR archetype;

7) *ResourceAgentWS* envelops the message containing the serialized object, and sends it to *ResourceAgentCCCM* coded in ACL. Following that, the patient's relevant information is displayed on a screen for the whole staff.

The tasks involved in this scenario are highly relevant for showing the benefits of delegation, namely efficiency and time management of the tasks. During the case study, we learned that end-users should be provided with both an intelligent-agent based interface and tools-based alternative, so that they have the option of either performing the tasks themselves or delegating them to others.

## VII. Evaluation

We employed the Technology Acceptance Model (TAM) [16] for evaluating the case study, given that it is appropriate a suitable model to explain the technology acceptance in the healthcare domain. TAM assumes that the *Perceived Usefulness (PU)* and *Perceived Ease of Use (PEU)* can predict the use and *Intentions to Use (IU)* of a particular technology.

To evaluate the acceptance of our case study, two groups of users were selected: 57 caregivers (including physicians, nurses, and medical students) and 122 patients. The caregivers were grouped together because they work as a team in this scenario.

The users utilized the system from 1st January to 30th July 2012, and following that a structured questionnaire based on TAM was sent to them. Respondents were asked to indicate their opinion with respect to several statements on a five-point Likert scale [17], ranging from 1 (strongly disagree) to 5 (strongly agree). Table 1 summarizes the results of this questionnaire.

TABLE I. TABLE TYPE STYLES

| Participants | Constructs | Number of Items | Mean |
|---|---|---|---|
| Caregivers | Perceived Ease of Use | 4 | 4.03 |
| | Perceived Usefulness | 5 | 4.35 |
| | Intention to Use | 3 | 4.11 |
| Patients | Perceived Ease of Use | 4 | 4.12 |
| | Perceived Usefulness | 5 | 4.50 |
| | Intention to Use | 3 | 4.15 |

Figure 9 shows the research model employed for this evaluation. The arrows are labeled with the hypotheses and the path coefficients, which measure the relative strength, and indicate causal relationships among variables.

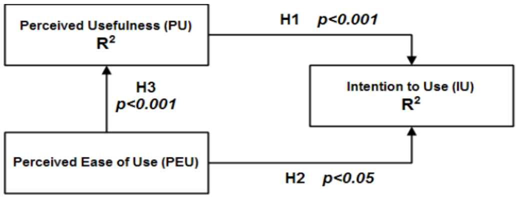


Fig. 9. Research Model

$R^2$ gives the percentage of total variance of the independent variables, and indicates the predictability of the research model. The following three hypotheses were proposed and tested in this scenario:

***H1***. PU positively affects the IU of the system.

- *Null hypothesis:* $\boldsymbol{H_{1n}}$: $\boldsymbol{\mu}_{PU} = \boldsymbol{\mu}_{IU}$.
- *Alternative hypothesis:* $\boldsymbol{H_{1a}}$: $\boldsymbol{\mu}_{PU} \neq \boldsymbol{\mu}_{IU}$.

***H2***. PEU positively affects the IU of the system.

- *Null hypothesis:* $\boldsymbol{H_{2n}}$*:* $\boldsymbol{\mu}_{PEU} = \boldsymbol{\mu}_{IU}$.
- *Alternative hypothesis:* $\boldsymbol{H_{2a}}$*:* $\boldsymbol{\mu}_{PEU} \neq \boldsymbol{\mu}_{IU}$.

***H3***. PEU positively affects PU.

- *Null hypothesis:* $\boldsymbol{H_{3n}}$*:* $\boldsymbol{\mu}_{PEU} = \boldsymbol{\mu}_{PU}$.
- *Alternative hypothesis:* $\boldsymbol{H_{3a}}$*:* $\boldsymbol{\mu}_{PEU} \neq \boldsymbol{\mu}_{PU}$.

To validate these hypotheses, we have chosen to apply Statistical Regression Analysis [18] over the data collected from the users. We tested $\boldsymbol{H_{3a}}$, and the regression analysis results were $R^2$=0.53 and $p$=0.0005, which is highly significant because $p$<0.001 and $\alpha$=0.05.

According to these results, $\boldsymbol{H_{3n}}$ can be rejected, meaning that PEU positively affects PU, and therefore $\boldsymbol{H_{3a}}$ is strongly confirmed. Since $R^2$=0.5, indicating that PEU explains 53% of the variance in PU, the hypotheses $\boldsymbol{H_{1a}}$ and $\boldsymbol{H_{2a}}$ can be accepted, and  therefore PU and PUE can be said to positively affect IU.

This evaluation showed that the communication system was useful in the users' daily tasks, and was easy to use by them. Furthermore, some usability benefits of this system, such as its efficient method of notification, were mentioned by most patients.

## VIII. Conclusion

An effective Pervasive Healthcare model requires that the exchange of information between the healthcare providers is both efficient and safe. This paper has presented an architecture that is based on intelligent agents and uses the *open*EHR standard to exchange messages in order to meet the requirements of interoperability between different HIS.

Message exchange with other systems is realized by integrating extracts of EHRs represented in terms of archetypes into ACL messages, which is a widely-used standard for information exchange between agents.

In our architecture, the intelligent agents are capable of performing human tasks that have been delegated to them, because of their cooperation and coordination capabilities combined with their ability to communicate.

We have also performed a case study in a realistic distributed healthcare environment. The case study was evaluated by both the caregivers and patients. This evaluation was performed according to the TAM model, and showed the acceptance of our proposal by end-users, which reacted positively in terms of its usefulness.

In further work, we will further evaluate the performance of our architecture, which is a crucial non-functional requirement for realistic applications and for the simultaneous support of multiple scenarios. We are also planning to extend the TAM model to evaluate the effect of others variables - such as, user experience and output quality - to moderate the effects of perceived usefulness and perceived ease of use on the intention to use.

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