vhMentor: An ontology supported mobile agent system for pervasive health care monitoring

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Abstract

Healthcare provision is a set of activities that demands the collaboration of several stakeholders (*e.g.* physicians, nurses, managers, patients etc.) who hold distinct expertise and responsibilities. In addition, medical knowledge is diversely located and often shared under no central coordination and supervision authority, while medical data flows remain mostly passive regarding the way data is delivered to both clinicians and patients. In this paper, we propose the implementation of a virtual health Mentor (vhMentor) which stands as a dedicated ontology schema and FIPA compliant agent system. Agent technology proves to be ideal for developing healthcare applications due to its distributed operation over systems and data sources of high heterogeneity. Agents are able to perform their tasks by acting pro-actively in order to assist individuals to overcome limitations posed during accessing medical data and executing non-automatic error-prone processes. vhMentor further comprises the Jess rules engine in order to implement reasoning logic. Thus, on the one hand vhMentor is a prototype that fills the gap between healthcare systems and the care provision community, while on the other hand allows the blending of next generation distributed services in healthcare domain.

Introduction – Related Work

Healthcare provision is a set of activities that demands the collaboration of several stakeholders (*e.g.* physicians, nurses, managers, patients etc.) who hold distinct expertise and responsibilities. Also, medical knowledge is diversely located and often shared under no central coordination authority to supervise.

Consequently, software modules and resources (i.e. hardware and human participants) of medical information systems are usually spatially and functionally distributed. Furthermore, data flow of medical systems across healthcare professionals, patients and other individuals (e.g. next of kin) remains quite passive, while the automation gap of administrative and assistance processes is recognized to be wide. In such an information intensive environment, we propose the vhMentor system, an agent-based and ontology-supported solution that employs software agents to process and monitor distributed medical data flows through concrete ontology-driven knowledge sources and provide them upon request to the end-users.

Accordingly, agent technology has proved to be ideal for developing healthcare applications, mainly due to its intrinsic characteristics of distributed operation over different systems and data sources of high heterogeneity. Agents are able to perform their tasks under a cooperation scheme by acting pro-actively in order to: i) assist individuals to overcome burdens posed by complex decision-making and ii) access medical data and non-automatic error-prone processes.

In a typical healthcare services provision scenario, patients are expected to be hospitalized in several facilities that subsequently provokes the produced data to be split across several diverse and non-integrated information systems. Orgun and Vu propose a multi-agent system combined with an ontology that defines and implements the HL7 vocabulary in order to facilitate patient data flow across the resources of a healthcare organization (Orgun and Vu, 2006). Liu et al. introduce an alternate integration approach, introduces the idea of a Virtual Integrated Medical information System (VIMS) (Liu et al., 2012). VIMS spins around a two layers integration scheme: (i) the data layer employs mobile agents to acquire and transmit medical data, (ii) the application layer is used to process the data acquired from various sources (HISs, medical devices etc.).

Another scenario of spatially distributed patient data is described by Martin-Campillo et al. (Martin-Campillo et al., 2009) where mobile agents are employed to query data from a Virtual Electronic Patient Medical Record (VEPMR) that is developed over a distributed medical database. Furthermore, on the basis of distributed e-health model, Pouyan, Ekrami, and Taban propose a multi-agent system where each human actor, device, software system and process is assigned to a mobile agent (Pouyan et al., 2011). However, the proposed solution fails to completely discard the client-server architecture of the legacy information system.

Moreover, the Java Agent DEvelopment Framework – JADE (Telecom Italia Lab, 2000) has attracted vast research community attention for its powerful task execution, composition and interoperability model. JADE allows for the peer to peer agent communication through an asynchronous message passing scheme while ad-hoc versions are designed to facilitate the deployment of agents on various Java-oriented devices such as Android. It is considered to be the most widespread and stable agent-oriented framework in use today. Furthermore, noteworthy research has been conducted on applying JADE framework in the field of health care. Su and Wu (Su and Wu, 2011) propose MADIP, a ubiquitous electronic health monitoring distributed information infrastructure. MADIP is a multi-agent system where each agent corresponds to a human actor in the real life process that allows for the automatic detection of patient data abnormalities both from the physician's and patient's perspectives. Kim et al. in (Kim et al., 2007) describe a context-aware healthcare system for effective management and automated services. A distributed service that is named K4Care is fully developed in JADE where agents are responsible to support knowledge and data dissemination in one hand and process execution in the other hand (Isern et al., 2011). Nguyen et al. propose an agent-based application (Nguyen et al., 2009), MEDIMAS, that aims to overcome the inefficiencies implied by legacy information systems (such as automation and mobility gap, manual information search, error prone processes etc.). MEDIMAS takes advantage of JADE mobile agents in order to enhance the operation of a legacy laboratory information system through an ontology that acts as a knowledge broker among the stakeholders. Mobile agents have also been applied in order to adopt medical sensors in a distributed paradigm (Vaidehi et al., 2013) and drug safety surveillance (Yanqing Ji et al., 2010).

In this work, we propose vhMentor, an ontology supported and agent-based system for healthcare data monitoring. Our objective is to propose a solution that covers the automation gap and at the same time avoids error-prone processes through a system atic and strategic approach of medical data delivery. Thus, we thoroughly study the applicability and usefulness of jointly applying the ontology framework and the mobile agent paradigm in the healthcare domain.

The rest of the paper is organized as follows. The next section introduces the main features of the vhMentor framework. In subsequent sections we outline our system's architecture and functional specifications and then we describe a use case scenario and system validation environment. The last section concludes our paper with suggested future research directions.

The vhMentor proposed framework

vhMentor is an agent-based framework with ontology support based on the JADE platform, the Protégé ontology tool suite and the Ontology Bean Generator middleware. Accordingly, the Jess rule engine is applied for carrying out reasoning tasks.

JADE is the multi-agent platform of choice because: (i) it is operating system independent and requires minimal resources to be executed on Java enabled devices (e.g. tablets, smartphones, etc.), (ii) it supports the development of JAVA software agents according to the FIPA specification (FIPA TC C, 2002), (iii) the ontology support of JADE allows the manipulation of information exchange between vhMentor agents as JAVA objects instead of ACL messages, and (iv) it provides the functionality to perform queries against complex ontological schemas.

A typical JADE deployment consists of the runtime environment, the agent development APIs and a suite of graphical agent management tools. Every instance of the JADE runtime environment is called a Container that act as agent hosts, which is the space where one or more agents may be created and exist. In order to create a new platform, a special Container, called Main-Container that plays the role of the coordinator, must be always active so that every other typical Container may register with it. In the event that a new Main-Container is initiated, it is

considered to be a different platform that may accept new containers through registration.

A middleware that binds together the JADE ontology support mechanism and the Protégé ontology development environment (Protégé, 2016) was necessary during the implementation of the prototype. BeanGenerator was selected as it allows the transformation of an ontology that is designed and developed in Protégé into JADE compliant JAVA classes.

Another significant component of vhMentor is the Jess rules engine that allows reasoning logic to be built under three programming schemes: fully developed in Jess, entire application implementation through a dedicated JAVA API or a mixture of them. Jess is a JAVA library fully interoperable with the JADE platform. Furthermore, research efforts have been devoted on studying integration of Jess with the semantic web rule language SWRL (O'connor et al., 2005) and their combined utilization in health domain applications (Chen et al., 2012).

The vhMentor architecture and functional specifications

The healthcare domain is mission critical and the intrinsic complexity of medical care activities stems from their distributed and fragmented nature along with their diversity and autonomy. The purpose of the proposed vhMentor system architecture is not to compare the advantages and disadvantages of the available technologies neither to benchmark the performance the agent-based approach against other implementations. vhMentor aims at process optimization through agents which are able to act as proxies either of human actors or medical devices that lack the computational resources for reasoning and management. Data management and monitoring, decision-making, multi-source information retrieval, dynamic, asynchronous and autonomous operation and fault-tolerance are only a part of the wide range of applications in the field.

The main feature introduced by vhMentor is to "listen" on health devices and sensors and disseminate the collected information through a well-defined knowledge ontology base. Patient information is managed by the Health Data Management Layer (HDML) which is responsible for collecting, storing, and broadcasting vital clinical messages to subscribers and is implemented through JADE agents. Namely, PatientMonitoringAgent and

device specific agents (i.e. TemperatureAgent, BloodPerssureAgent, LightAgent) act as brokers between the sensors, the service agents layer (i.e. Health Information Layer - HIL) and the Jess Agent.

HIL is designed to cope with real-time data requests and queries from the end-users against ontological and knowledge bases. This layer performs the interpretation of health information related content to personalized medical actions (i.e. DeliverResultsAgent, ExaminationAgent, AskForResultAgent) or alarm generations (i.e. CgAlertAgent, NotificationAgent). Thus, care providers are able to review the status of the patients through the software platform. HIL provides to daily medical practice features such as dynamic interaction, continuous data update and cooperative management. Also, it allows for maximum customization, so as medical, nursing and technical staff can easily adapt by adopting a digital mode of operation in patient monitoring. Fig. 1 depicts the conceptual design of the vhMentor system along with its main components and the interactions of the aforementioned functional modules.

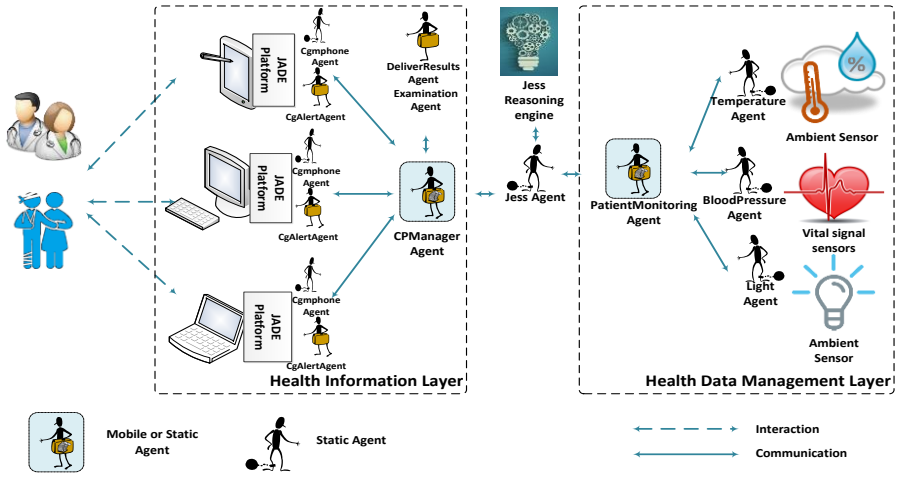

Fig. 1: The conceptual model of vhMentor

Use Case Scenario and System Validation

Every healthcare monitoring ecosystem consists of patient bio-signals, environmental and accelerometer/gyroscope sensors. Although generated data forwarding are either “pushed” and “pulled”, within the scope of

this work we study the “pull” mode of operation as it is more complicated and operates by gathering all necessary data upon request. On the contrary, the “push” mode of operation simply transmits all sensed data to the processing center. The HDML stores the information – measurement sent from each sensor’s static agent (see Fig. 1). In parallel, depending on their assigned role, practitioners and family members have access to medical/health data through a delegated agent that resides on the networked device they use (i.e. CgmphoneAgent). Sensed data are forwarded to the JessAgent so as to be further processed by a reasoner engine, in order to diagnose, advise or alert for each individual patient. Upon processing the data of the HDML layer, HIL can inform practitioners or family members through their personal proxy agents (i.e. CPManagerAgent and CgmphoneAgent) about a patient’s medical condition.

In order to verify the validity of the ontological model (Fig. 2) that is proposed for healthcare monitoring we translated it to JAVA classes that were embedded in agents implemented over the JADE platform. Subsequently, we developed an experimental environment that implements the scenario described above. More specifically, each sensor (i.e. ambient and vital signal) is simulated through a static JADE agent that is also dedicated to collect and transmit the sensed data whenever requested. The CPManagerAgent is the central processing module of vhMentor. At least a CPManagerAgent has to be active in a typical vhMentor deployment. Each caregiver owns a delegated agent that is named CGmphoneAgent and acts on his/her behalf. Other individuals that should participate (e.g. patients, family members etc.) are represented by CGmphoneAgent instances too.

A command line menu provides a set of 6 options as provided in Fig. 3. The first option creates a Computerized Patient Record (CPR) and contains a patient’s personal health data. Upon its creation a unique code and a default alias is assigned. In future implementation it will also hold demographic data, such as address, phone numbers etc. By using this option we created 3 patients (i.e. *patient0, patient1* and *patient2*). Then, we simulate the operation of ambient and vital signal sensors and we assign to the actor agent of *patient2* sample temperature and blood pressure values through the *“Make a temperature measurement”* and *“Make a blood pressure measurement”* menu options respectively. Subsequently, the *“Get the most recent patient's values”* collects all the data that are already assigned to a specific patient CPR.

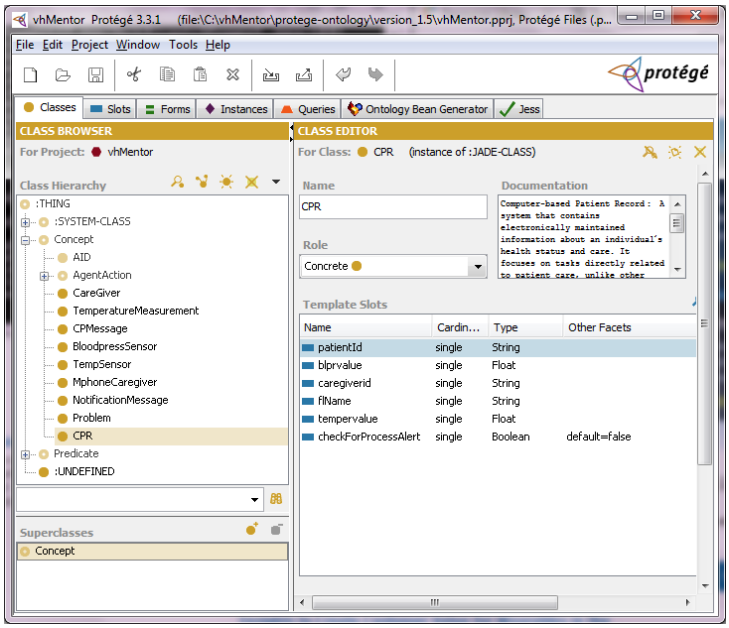

Fig. 2: The vhMentor ontological model in Protégé tool suite

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<<---- PATIENTS- MENU ---->>
         1. Create a new patient
         2. Make a temperature measurement
         3. Make a blood pressure measurement
         4. Get the most recent patient's values
         5. Get the list of temperature measurements
         6. Get the list of blood pressure measurements
```

Fig. 3: The command-line main menu of the proposed system

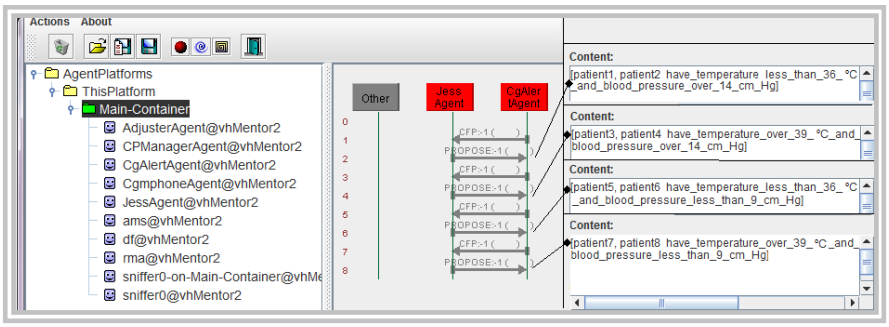

Fig. 4: An example of the vhMentor execution and the resulting messages within the Jade Sniffer environment.

The Jess engine through the delegated actor JessAgent employs data and information provided from the HDML and HIL layers respectively along with decision-making and health advising logic that is defined in Jess rule language. An example of the vhMentor execution is depicted in Fig. 4 and exhibits its reasoning capabilities towards combining knowledge of rules and the vhMentor ontology.

Conclusion and Future Work

We proposed vhMentor, a system that employs an ontology supported and agent implemented framework for applying ubiquitous patient monitoring. vhMentor is a platform independent health-care provision framework built on top of the well-established JADE platform, the Protégé ontology tool suite, the BeanGenerator middleware and the Jess rule engine. Their respective interoperability-oriented, scalable and heterogeneity bridging libraries allow for faster, fault-tolerant and optimized implementations than “custom” ones. In parallel, we introduced the methods so as sensing technology and devices to be included in an ontology-based healthcare information system. The outcome of this framework is an efficient system that allows for the introduction of next generation services (e.g. decision making and reasoning) through autonomous and intelligent agents.

vhMentor is expected to improve the offered healthcare quality by integrating the notable evolution in sensor technologies and knowledge management. Also, healthcare providers are able to actively monitor pre-hospital, hospitalised and ambulatory patients with the help of the agents.

Our future work includes the development and implementation of a prototype for the automatic correlation of healthcare and environmental measurements with care plans through a reasoning engine.

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