Multi-Agent Systems for e-Health and the CASCOM Project

Federico Bergenti and Agostino Poggi

Abstract—**e-Health services and applications are probably one of the notable application fields where agent technology might act as a main actor in the near future. Multi-agent systems have been devised to deal with classes of problems–e.g., remote and heterogeneous software integration, remote monitoring and assistance–that are very typical for the large part of e-health services and applications. This paper describes some of the main reasons why multi-agent systems are now considered one of the best solutions for the realization and deployment of advances e-health software. The paper motivates this claim by addressing very general issues that have been previously identified as key problems of e-health. The paper is structured in two main parts. The first introduces the technological problems that characterize e-health and it shows how multi-agent systems tackle them. The second part describes an important European scale project that has recently adopted multi-agent systems to realize an e-health application scenario, i.e., decentralized emergency assistance.**

Index Terms—**Agent-oriented software engineering, e-Health systems, m-Health systems, Cooperative systems.**

I. Introduction

MULTI-agent systems (MASs) are one of the most interesting fields in software research that have been contributing significantly in the past few years to the development of the theory and practice of complex distributed systems. Healthcare applications and services seem to be very suitable for taking advantage of MASs: *(i)* they are composed of loosely coupled, complex, heterogeneous, legacy systems; *(ii)* they manage data and resources that are inherently distributed; and *(iii)* they are often used by disperse users in (synchronous) collaboration.

The goal of this paper is to describe the main reasons why MASs should be considered one of the most interesting technologies for the development of healthcare systems. The paper also provides some guidelines to identify which kinds of healthcare applications can truly take advantage of MASs features. Then, the paper presents CASCOM [13], a recent European-scale project that adopted MASs to realize and field-trial a decentralized emergency assistance scenario.

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II. Agent Technology and e-Health

There is common agreement in the field that the buzzword *e-health* was introduced in 1999 as a consequence of the *e-** mania to talk about the provision of healthcare services through the Internet [11]. Notably, this buzzword was heavily promoted by the industry and by application and service vendors and soon the academic community started using it instead of the over-abused telemedicine. Such a widespread adoption of this new word was so wide and deep that anything that had to do with technology and health was quickly included. In order to clarify the obvious misunderstandings that immediately arose and to support such an important idea, the European Commission itself felt the urge to provide a common and generally acceptable definition of the word e-health as: *“the use of modern information and communication technologies to meet needs of citizens, patients, healthcare professionals, healthcare providers, as well as policy makers.”* [7]

Besides the clarity–or possibly the confusion, someone may say–that the mentioned definition created, it is common understanding that e-health uses ICT for the provision of health-related services to sparse users, possibly on the move. This pushed interaction and communication as central to e-health and it immediately promoted agents-related technologies as ideal candidates to support next-generation e-health services and applications.

Similarly, e-health deals naturally with mobile users, e.g., in tele-assistance scenarios, and it is common understanding that e-health should accommodate transparently fixed and mobile users. So called *m-health* is another buzzword that has been recently proposed to stress this fact: m-health services should be accessible anyone, anywhere, anytime, anyhow, and *any*-***. Fortunately, such characteristics are already common practice of agent technologies; e.g., JADE [4, 9] and JADE-LEAP [5] do take special care of transparently and dynamically allocating fixed and mobile users and agents.

Another important issue in e-health is about supporting the interoperability of (legacy) medical information systems in order to enable the integrated provision of advanced services capable of accessing information from different, remote sources. The dream of a single, universally accepted middleware supporting the development of new services and the renewal of legacy services was quickly abandoned and recent technologies that were originally intended to support the (semantic) interoperation between heterogeneous services was quickly adopted and now is common practice. This, again, put agent technologies into the group of technologies capable of providing important contributions to e-health because of the inherent semantics-awareness of the interaction between agents that make them ready to deliver semantic interoperability.

Another important issue that most e-health services address regards the possibility of jointly supporting professionals in their highly specialized work. Computer-Supported Cooperative Work (CSCW) is already common practice in tele-surgery and tele-assistance and it seems an important ingredient of next-generation e-health services. Notably, the inherent cooperative nature of agents and the very fact that many CSCW technologies are already based on agents is another important contribution to the view of agent technologies as first-class citizens of e-health.

Similarly, another notable contribution of agent technologies in the development of next-generation e-health services and applications regards the central venue that security and privacy-awareness have in agent technology. In the agent realm, the issues of privacy-awareness are threaded under the umbrella of the more expressive notion of trust. Likewise, e-health strongly remarks the importance of preserving confidentiality and guaranteeing a high level of security for classified information about patients.

Even if the mentioned facts regarding the adoptability of agent technologies for next generation e-health services and applications can be convincing, we try to sustain our statement by adapting the well-known grouping criteria proposed in [3]. We say that agent-technology contributes to next-generation e-health from three points of view: *(i)* improving the quality of healthcare, *(ii)* facilitating the access to healthcare, and *(iii)* reducing costs.

The most important contribution that agent technology can provide to the overall quality of healthcare relies essentially on the possibility of feeding highly specialized healthcare professionals with the right information, at the right time, tailored to the patient. The proactive nature of agents and their semantic interoperability support such a need with the possibility of feeding users with information acquired from diverse sources and tailored to the concrete patient at hand. Thanks to the computerization of health records, that is now common practice in Western Countries, the transfer of complex health records globally and in real time increases the accessibility, unifies the information at every stage of complex healthcare processes and improves care continuity. Moreover, the longstanding tradition of expert systems that still lives behind the scenes of some agent technology can support healthcare professionals in using the provided information for taking the right decisions at the right time. Finally, the transparent integration of mobile terminals helps collecting data to quickly support contextualized decisions.

Notably, the scenario of allowing a quick and contextualized access to healthcare-related information from anywhere, at anytime and in the most convenient way can promote the long waited universality and equality of access to healthcare, especially for geographically or socially isolated patients. Such cases are extreme and they may seem visionary for the current lack of supporting infrastructures, e.g., communication networks and power supplies, but the inherent transparent decentralization that is always assumed in contemporary agent technologies is vital to facilitate the access to healthcare also in everyday scenarios. This is the case, e.g., of homecare to elderly, disabled or chronic patients. The widespread adoption of agent technologies at homes can help drastically reducing medical visits and related waitlists. Moreover, the proactive nature of agents helps creating a trusted link between agents and patients by having agents constantly pushing valuable information to patients with no need of explicit demands. Agents are good tools to help patients following preventive strategies and supporting self-care on a day-by-day basis.

The last grouping criterion that in [3] is about cost reduction of healthcare processes. This is an issue of notable importance for the inherent costs of quality healthcare and agent technologies are beneficial also from this point of view. The mentioned possibility of agents to provide the right information, at the right time, tailored for the patient supports efficiency the overall management of treatments. Moreover, the semantic interoperability of agents enables instant acquisition of information from its natural source, with minimal (if not null) pass of information along chains of intermediaries. Finally, the trusted and privacy-aware support that agents provide to healthcare processes is a valuable means to speedup and optimize many administrative procedures. All in all, we can summarize the contribution that agent technologies can provide to healthcare, from the point of view of cost reductions, with an earlier assistance and a structured prevention of the causes of further care.

III. The CASCOM Project

The EU funded project CASCOM [13] is one of the most recent attempts to bring the notable characteristics of agents to e-health. CASCOM is a technology-driven project that brings together three notable new technologies: MASs, semantic Web services and Peer-to-Peer (P2P). It finds its motivations in the following healthcare scenario, that was ran in many occasions throughout all Europe. The scenario involves Juha, a Finnish, who is abroad in Austria for business. Before leaving Finland, he loaded the CASCOM mobile agent suite on his mobile phone so that he can access CASCOM agents anywhere, anytime. Suddenly, he feels severe pain in his chest and he decides to call for help via his CASCOM personal agent in order to make his ignorance of German irrelevant. The agent prompts a few questions on Juha's phone screen and it forwards such information–in parallel–to the local emergency dispatch center and to the Finnish Emergency Medical Assistance service center (EMA). The agent contextualizes such information with Juha's current location and personal identification data. Such contextualized information allows the dispatch center immediately sending an ambulance down to

Fig. 1. Main parts of the CASCOM technology (from [13]).

Juha. On the road towards its destination, the CASCOM agent hosted on the mobile device of the physician on the ambulance selects and invokes the semantic Web services–physically located in Finland–that provide access to Juha's medical history. Thus, the physician on the ambulance can easily get an in-depth overview on Juha's health state on the way to the patient, without having seen him before. Once at destination, the ambulance takes Juha to the selected hospital and CASCOM agents are used to help the physician in acquiring the needed information to support his local supervision of Juha's health. Finally, just if needed, CASCOM agents are used to organize Juha's repatriation, by contacting needed semantic Web services for booking medically-equipped flights, and to exchange information between healthcare organizations in the process of his after-treatment.

From a functional point of view, CASCOM motivating scenario addresses well-known issues of emergency healthcare. Actually, a major challenge in emergency healthcare is to take the best decision on the treatment of the patient, with no background knowledge of the patient's medical history, e.g., known allergies and current medical treatments. CASCOM addresses such needs by providing physicians with contextualized information on the fly. Such information is acquired as needed directly from its source because CASCOM agents interact directly with the semantic Web services that organizations provide to access needed information in a secure and privacy-aware manner. This is by far a visionary scenario, because many organizations (see, e.g., [14]) are now in the process of opening their information systems via semantic Web services to allow foreign physicians to access patients' data, especially in emergency situations.

From a technological point of view, the distinguishing feature of CASCOM approach regards its openness and dynamism. Notably, no a-priori link is set between agents and/or semantic Web services and the pattern of communications is structured on the fly to satisfy the goals of agents. Similarly, the CASCOM service discovery agent identifies all relevant services and respective providers by means of the directory services hosted at EMA. Afterwards, the CASCOM planner agent creates an ad-hoc plan which composes the invocations to the services identified in the previous step. The CASCOM execution agent finally invokes all services specified in the plan and it applies failure handling mechanisms, just when needed. For the case of the motivating scenario, this includes accessing the healthcare information system that store Juha's medical history, which is located at EMA. As a result of this dynamically composed ad-hoc plan, information on Juha's medical history is collected–potentially from different sources–and transferred to the agent running on physician's device.

It is worth mentioning that CASCOM motivating scenario heavily uses one of the distinguishing features of agents that we mentioned in the previous section. Agents are flexibly deployed on fixed and mobile devices and they communicate using wired and/or wireless links on the sole basis of their current goals. For example, the physician's agent is initially started on the base station of the emergency center where a WLAN connection is available. As soon as the emergency car leaves the base station, it also leaves the connection range of the WLAN and the agent communication is seamlessly migrated to UMTS.

The main delivery of CASCOM project is a general-purpose, open-source middleware that implements a generic architecture for agent-based coordination and execution of semantic Web services in a so called Intelligent Peer-to-Peer (IP2P) network, i.e., a decentralized network of loosely coupled, proactive peers with no restriction on the actual means of connectivity. Such architecture transparently accommodates both mobile and fixed users into a seamless environment. In short, the CASCOM architecture provides easy, seamless and contextualized access to semantic Web services anytime, anywhere and using any device. The main ingredients of CASCOM architecture are depicted in Figure 1.

CASCOM architecture relies on a layered approach. The four main components of this architecture link the application layer with the underlying networks and are described in some detail below.

The Networking Layer provides a generic, secure, and open IP2P network infrastructure taking into account varying quality of service of wireless communication paths, limitations of resource-constrained mobile devices, and contextual variability of nomadic environments. In details, it provides the following functionality:

1) Efficient, secure, and reliable agent message transport communication over wireless (and wired) communication paths independently of the access technology;
2) Provision of network-related context information to the context subsystem;
3) Low-level service discovery; and
4) Agent execution environment for resource-constrained mobile devices.

Setting out from the services of the Networking Layer, and based on the functionalities offered by both the Context-Awareness and the Security and Privacy subsystems, the Service Coordination Layer takes an agent-based approach towards flexible semantic Web service discovery and coordination. Its main functionality is twofold:

1) Semantic service discovery, i.e., service discovery and semantic matchmaking; and
2) Service coordination, i.e., service composition, execution, and possible re-planning.

The Context subsystem, orthogonal to the layers described above, is in charge of acquiring, storing, and providing context information to both those layers.

The Security and Privacy subsystem, also orthogonal to the Networking and Service Coordination layers, is responsible for ensuring security and privacy of information throughout the different parts of the infrastructure. One of the main things we need to protect is the data that every node of the IP2P network maintains. In details, data confidentiality, integrity, and availability are topics of concern that any approach to security must address. The security and privacy functionality was considered at every level of the CASCOM architecture. This enables instant take-up of the CASCOM concepts for service-oriented business applications.

The use of agents to support nomadic computing has been intensively studied in the past few years and CASCOM builds on previous results by using a well-known and appreciated agent platform, i.e., JADE-LEAP [5], as the basis for the implementation of its architecture. Unfortunately, JADE-LEAP did not really take into account many P2P issues and the CASCOM project had to address them explicitly. This concerned the realization of a novel support for communication that does not make any assumption on the actual physical and logical topology of the network and it does not even require the availability of a special node acting as a bridge to the fixed network.

IV. Conclusions

According to Altman [1], one of the ten infrastructure challenges that Artificial Intelligence has to face to provide valuable contribution to healthcare regards having medical records "*based on semantically clean knowledge representation techniques.*" Agents not only provide the needed tools to turn such a challenge into reality, but they also provide a clean way to make such records available anywhere, at any time. This is a notable improvement of the proposed challenge and agents are ideal means to achieve it.

Moreover, we agree with [2] and we believe that a key component of the "*smart use of computation*" that authors mention will be the use of agent technology. Agents will improve healthcare organizations and will also support doctors and caregivers. However, we also agree on the mentioned issues regarding the impact of the use of agent technology with patients, which will not only be an improvement but a radical change in how healthcare and assistance will be provided. Unfortunately, the adoption of agent technologies within e-health is taking place quite slowly and, despite the number of research projects on the topic, this by far an assessed practice. We believe that the main reasons for this are not in the agent technology itself, which is generally well accepted; rather they originate from the inherent difficulties of having ICT accepted in healthcare from the technical, social, political, legal and economical points of view. This is a well discussed topic in the literature and interested readers can refer to some notable works [3, 6, 8, 10, 12, 15].

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