A Multi-Agent Solution for the Interoperability Issue in Health Information Systems

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***Abstract*—To achieve high quality and efficiency standards, interoperability between different information systems in healthcare is strongly required. Distribution, high modularity, robustness are features of agent oriented architectures, making Multi-Agent Systems (MAS) ideal for Health Information Systems (HIS), as the healthcare domain is characterized by system and data heterogeneity. This paper presents an agent oriented architecture to address this kind of issues, capable to access geographically distributed data to allow health professionals to retrieve/update any patient's record efficiently and reliably. The proposed architecture is composed by three layers, to allow local data storage keeping clinical information available by authorized facilities and physicians. Furthermore MAS technology integrates with legacy systems, wrapping them with agents.**

I. Introduction

The healthcare domain is facing a growing number of challenges: the incidence of medical errors is rising; many medical facilities are understaffed, and serve increasingly large areas; healthcare costs are rising more and more; healthcare facilities are under pressure to provide better services with less resources [1]. The median age of population is increasing, resulting in a rise in the number of chronic diseases and thus of health-related emergencies [2]. Health Information Systems (HIS) can provide a better coordination among medical professionals and facilities, reducing the number and incidence of medical errors [3]. They are considered as a solution to assist physicians in tracking patient medical history, interventions, encounters and lab test results [4]. In the same time, they can reduce healthcare costs and may provide a means to improve the management of hospitals [5], [6]. Unfortunately, due to the inherent complexity of their application domain, HIS are fragmented in various systems that hardly make use of communication standards, process definition protocols and homogeneous data representations. Thus international boards and local governments are defining general requirements for HIS and supporting the adoption of health information technology ([7]), to provide sustainable and effective healthcare services. Italian Health Ministry, following European Union (EU) directives, defines the requirements for the "Basic Infrastructure for Electronic Healthcare" [8]:

- *localization and availability of health records*. Patients' clinical information should be available 24 hours a day and 7 days a week, wherever data are stored.
- *Federated architecture*. Healthcare facilities and services are distributed and federated by nature, and clinical data should be maintained in the facility where they are produced, ensuring that information will be updated when necessary.
- *Security and privacy*. Due to the importance and the strictly personal nature of clinical data, information should be processed by mean of secure architectures, addressing privacy laws.
- *Scalability, modularity and reliability*. The infrastructure should be modular, to avoid a quick obsolescence, and scalable, to support the growing number of medical records; a HIS should be designed to achieve a safety critical degree of reliability.
- *Integration with legacy systems*. HIS architecture should integrate with existing systems in order to preserve past investments and to make its adoption practicable for local facilities.
- *Use of open standards*. It is, in fact, a mandatory requirement for those systems, as HIS, addressing interoperability issues.

Multi-Agent System (MAS) paradigm, being characterized by decentralization and parallel execution of activities based on autonomous entities [9] with social ability [10], could be ideal to implement HIS that respond to the needs of the healthcare domain: fields such as information access, decision support systems, internal hospital tasks would gain the greatest advantages from the typical distribution of agent technology and the existing standardization of communication between agents [11].

A. Our Contribution

In this paper we propose an agent oriented architecture capable to access geographically distributed data to allow health professionals to retrieve/update any patient's record efficiently and reliably. Such architecture meets the interoperability requirements among different health facilities and, at the same time, integrates with existing legacy systems (including local databases), being a new software layer on top of existing ones: this allows to protect the investments made by facilities and institutions as required by ministerial directives [8], in addition to address interoperability issues.

The main advantages of such architecture are:

- *Distribution*. A key concept of agent technology is flexibility: the complex issues of interoperability and integration with existing systems is broken down to minor tasks assigned to individual agents: cooperation is the solution to the original question. Retrieving data is possible from any point in the territory just through communication of distributed agents, and expensive infrastructures - as happens with cloud solutions - are not required.

- *High modularity*. Thanks to standardization activities made by the MAS community - FIPA IEEE -, simply adding new agents in the architecture (registering their services and sharing the same ontology) is enough in order to extend the capabilities of the system.
- *Robustness*. An agent oriented infrastructure provides many recovery techniques to better achieve fault tolerance goals.
- *Integration with existing systems*. With the aid of wrapper agents, each one designed for a particular instance of legacy information systems, the architecture represents a higher fully interoperable software layer. Communication at this level is readily able to use well established standard ontologies for messaging (HL7), definition of clinical documents (HL7 CDA), scheduled workflows (IHE) and health care terminologies (such as LOINC and SNOMED CT).

B. Paper Structure

The rest of this paper is organized as follow: section II describes related works, about HIS and adopted technologies to implement them; section III details the multi-agent system architecture; section IV illustrates an implementation related to an emergency-response scenario; section V points out some qualitative evaluations about the proposed architecture; finally, section VI draws the conclusions from the described work.

II. Related Works

In recent years, two different technologies have been the subject of much of the research relating to HIS: cloud computing and multi-agent systems. A mobile system that enables electronic healthcare data storage, update and retrieval using Cloud Computing is proposed in [12], in which a mobile application based on an Android client enables the users to retrieve remotely health information and images. In [13] a wireless sensor network is used to automate the data collection process. The collected information are distributed through a Cloud Computing solution to medical staff. An alternative approach is proposed in [14], where data and service interoperability is obtained through a distributed and agent-oriented system. [15] and [16] use the multi-agent system technology to support the home-care monitoring and treatment of patients. In [17] software agents are developed as personal assistants for physicians and administrative staff, trying to free them from routine work.

Also researches about HIS impact have been carried out. In [4] several papers concerning HIS and their implementations are examined in order to understand factors and influencers from previous experiences. In [18] scientific literature is investigated in order to provide a conceptual basis to understand and address HIS success and failure. The work in [19] analyses positive and negative findings in HIS research, remarking the lack of reports about negative results, necessary to assess benefits of HIS. Finally formal ways to design and develop HIS are necessary since the wide introduction of health information technologies can lead to new types of errors (see for example [20], [21]).

III. Infrastructure

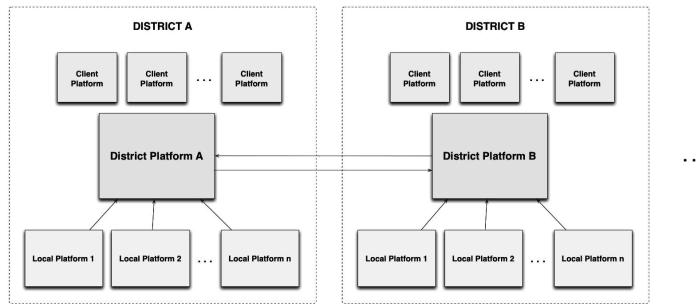

Fig. 1. The global architecture is structured in three logic layers.

The agent oriented architecture is expressed by three levels of abstraction, named local platform, district platform and client platform (Fig.1-2): each one is characterized by its specific agents and resources as described in the next subsections. The discriminating factor between the first two layers is of administrative nature: there is a local platform for each health facility in the territory (e.g. a hospital); facilities refers to administrative districts, which constitute the second layer of the architecture; finally, the client level is represented by any software agent which needs to login to the infrastructure to retrieve documents or insert/update a patient's health record.

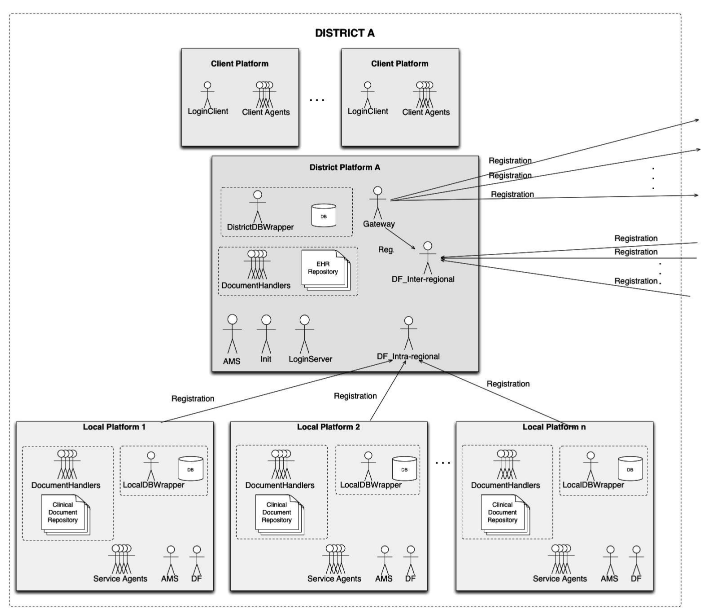

Fig. 2. Relation between local platforms and their referring district platform.

A. Local Platform

There is a local platform (Fig. 3) for each health facility. It has the role to interface with any information system, currently

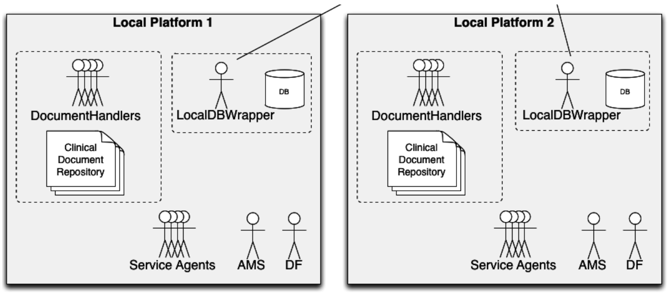

Fig. 3. Local platform agents.

present in the structure, committed to the management of clinical documents (create, edit, search, access) and the scheduling of different departments in the facility. Every local platform needs to know the address of its referring district platform in order to have access to the entire agent infrastructure.

LocalDBWrapper.: The task of such agents is to interface with the databases of a certain local healthcare institution. The advantages in the use of wrapping agents are the following:

- All the legacy systems would not be modified or replaced, but in fact encapsulated within such agents. In this way, any external agent, which needs to access to data contained by a local database, will be able to obtain them simply by communicating with the referring LocalDBWrapper agent, thus avoiding direct interaction with legacy systems.
- It makes possible to abstract the actual data representation within the different information systems available in the various facilities. With this solution, we don't need to address issues like information conflicts (such as homonymy and synonymy) or data schema inconsistencies by burdensome techniques of renaming, restructuring or even system redesign; it is sufficient to design a wrapping agent for each different legacy system able to translate the internal data representation in the ontology shared by all the agents in the infrastructure.

Hence, using agents to wrap local databases allows to keep data in the local facilities where the medical records are generated, differently from outsourced cloud solutions that store data in remote servers and have to deal with privacy concerns [22]. Furthermore agents have proven useful when directly acting as Web Services, providing agent-based services [23]. An agent that needs data from the LocalDBWrapper is able to obtain the service with a message exchange in the FIPA Agent Communication Language. In order to add a local platform to the entire agent oriented architecture, the LocalDBWrapper agents must register to DF_Intra-District agent of their referring district platform: this makes it available from distributed and remote agents, which need to retrieve data contained by the local structure.

DocumentHandler.: This kind of agents are able to access the content of a specific clinical document produced within the facility, such as clinical reports, laboratory tests, prescriptions, etc. In general, a DocumentHandler is contacted by a client agent to get health records managed by it: the DocumentHandler agent locates the requested document through its unique identifier, obtains it from the clinical repository and translates the information in an outgoing message towards the requesting client agent. Hence, the latter will be able to get the contents of clinical data requested.

Service Agents.: This set consists of agents for the management of different departments of the healthcare structure (e.g. radiology, cardiology, analysis laboratory, etc.). This paper does not provide further information on this field, but it is possible to find details about an agent oriented implementation of the Radiology Scheduled Workflow provided by Integrated the Healthcare Enterprise (IHE) consortium in [24].

B. District Platform

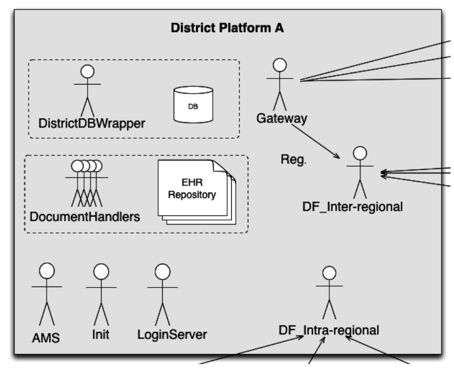

Fig. 4. District platform agents.

The main task of a district platform (Fig. 4) is to encapsulate all the local platforms that administratively belong to it. Basically, the district platforms represent the logic layer which composes the final architecture and allows to achieve the interoperability goal of our distributed system: every district platforms, therefore, must know each other their address.

DistrictDBWrapper.: These agents have similar functions with local wrappers: they manage data within district databases. The gateway agent contacts wrappers in order to store or retrieve any reference to a patient's clinical records, which have been produced by every local platform in the territory or by general practitioners.

DocumentHandler.: DocumentHandler agents manage those kind of documents which are of administrative competence of a district, such as Electronic Health Record (EHR) and Patient Summary [25]. They may refer to health records which are distributed in different local platforms: the Gateway agent has the role to look for and gather this information.

Gateway.: The Gateway agent catches the client requests and makes queries to local and district wrappers to retrieve data about any distributed health record of a citizen (Fig. 5). It returns the addresses of DocumentHandler agents which the client must contact to get the required documents. To accomplish this task, the gateway performs two basic activities:

- When it retrieves the distributed data required to fulfil a client request, it must integrate them into a data structure, so that the client can handle a single dataset.
- When a clinical record is produced within a district for a patient belonging to another district, the former

gateway must inform the latter one to make its referring DistrictDBWrapper agent register such event in its own district database.

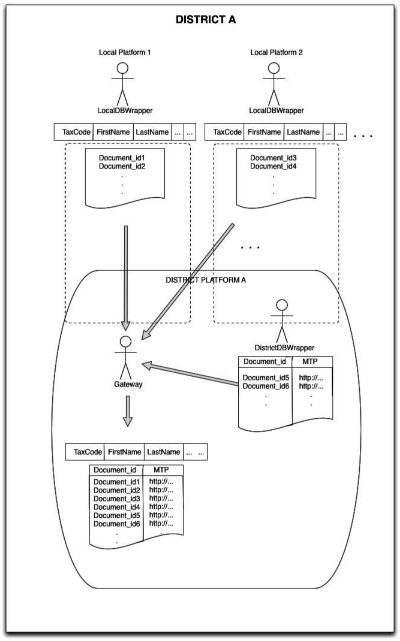

Fig. 5. The Gateway agent retrieves the location of health records within the system.

Init.: During the starting phase of the district platform, the Init agent registers the same platform Gateway to all the active DF_Inter-district agents of the remote district platforms in the territory.

DF_Inter-district.: As we just said, it is the Directory Facilitator in which all the remote Gateways are registered. This allows a single Gateway to communicate with any other distributed gateway in the entire infrastructure.

DF_Intra-district.: This Directory Facilitator contains all the LocalDBWrapper agents registrations of the local platforms belonging to the same district.

LoginServer.: Its task is to establish a secure connection with the client that wants to access to the infrastructure to retrieve data in a specified district.

C. Client Platform

This logic platform contains client applications, which may be any agent oriented software that is able, after a login phase, to access data through the connection with a district gateway agent. Examples of client applications could be: software to access EHR, both by medical staff and citizens, mobile applications to retrieve the Patient Summary for emergency situations, software to update health records by general practitioners, etc.

IV. Scenario

To show the capabilities of this architecture we assumed a scenario where an emergency doctor urgently needs to consult a patient's health records, in particular his patient summary. According to the EU definition, a patient summary is a clinical document that is digitally stored in repositories with cumulative indexing systems and secure access by authorised people. It is an HL7 CDA compliant document, contained in the patient's EHR, whose purpose is to summarize a patient's clinical history and his current situation.

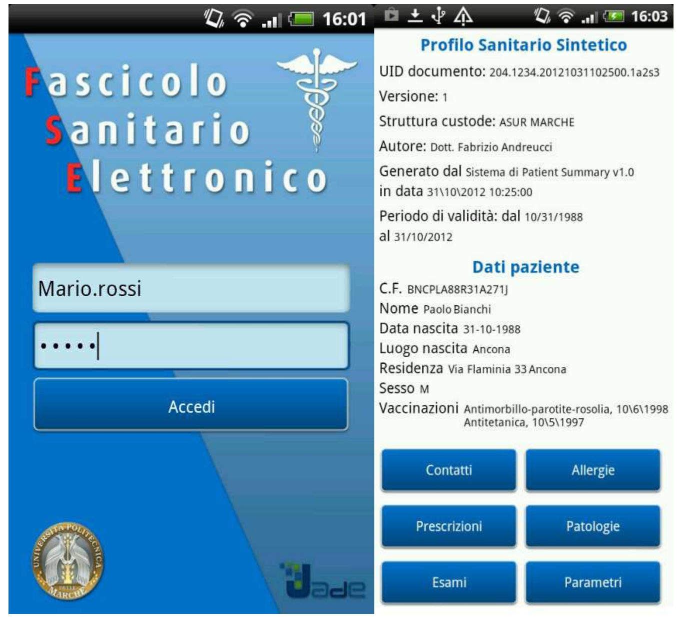

Fig. 6. Login and main screen of mobile application for the Patient Summary.

In short, the main Patient Summary's use cases can be summed up in [26]:

- Emergency situations in which the patient may not give an exhaustive description about his clinical history (problems, allergies, current medicines, etc.).
- Reliability of the information flows between family doctor and health facilities.
- Patients affected by chronic diseases managed by several specialists or elderly in home care regime.
- Diagnostic process support, telemedicine, etc.

Finally, the Patient Summary contains both mandatory and optional fields, and it is expressed through XML markup language.

To build such scenario we used:

- JADE Framework [23] to develop local and district agents in some desktop computers.
- An android smartphone application (Fig. 6) to simulate the client agent, developed with JADE LEAP add-on.
- Ministerial directives to compose a Patient Summary for our experiment, an XML parser and an agent ontology based on HL7 concepts.

The operating mode is very simple (Fig. 7). First of all, the mobile client application log in to the district platform entering its username and password: a secure connection is established with the platform using TSL protocol to ensure secure access to patients' personal and sensitive data. Then, the client asks for a citizen's Patient Summary and its relative health records by typing his tax code: the Gateway agent will query the different distributed entities to find the location of required data and inform the client where it can retrieve health records. Finally, the client application gather this data asking directly to DocumentHandler agents of the platforms which hold the patient's records.

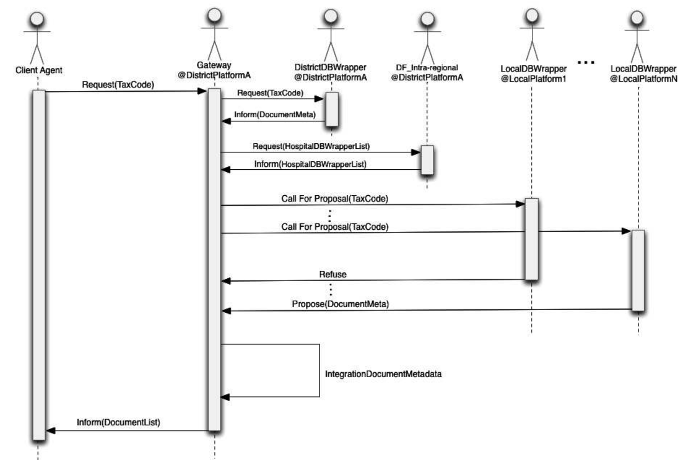

Fig. 7. The client agent queries the infrastructure for a citizen's health records.

V. Evaluation

Since the proposed MAS has to be understood as an infrastructure to address the interoperability issue in HIS domain and we implemented a simple proof-of-concept for a specific use case scenario, a quantitative evaluation is impossible at this stage of the work. Nevertheless a qualitative evaluation about the benefits produced by the adoption of MAS can be outlined.

The standardization of agent communication permits to integrate legacy system and new services wrapping them with agents, achieving interoperability and modularity. The JADE framework, adopted for our emergency scenario, adheres to FIPA standards allowing agents to register their services in a Directory Facilitator (DF) agent. Hence, other agents can query the DF to obtain the services they need. Also reliability and robustness can be achieved with MAS approach: keeping the focus on JADE, the framework offers the Main Container Replication Service (MCRS) and the DF persistence; in this way the container responsible for agent management is not a single point of failure and offered services are always traceable.

Some domain experts[1] have concerns about the actual applicability of our Multi-Agent approach in present HIS for which Service Oriented Architectures (SOA) are widely adopted. In our opinion an integration between MAS and SOA is both possible and desirable. Furthermore W3C specifications about Web Services confirm that software agents are the running programs that drive Web services both to implement them and to access them [27].

[1]as Klaus-Peter Adlassnig, during the final panel of the 1st International Workshop on Artificial Intelligence and NetMedicine (NETMED'12)

VI. Conclusion

In health information systems, the importance of addressing interoperability issues among existing systems is widely recognized. A crucial aspect is to allow health professionals to get any information they need about a patient in a pervasive and reliable way, even if these data are distributed in technically and geographically different health information systems.

To meet these requirements, in this paper we proposed an architecture based on MAS technology that takes advantage of the adoption of established standards for the management of clinical documents. Our goal was to show how MAS features can contribute in HIS in terms of interoperability, reliability, modularity and robustness; and how health professionals - and thus citizens - could benefit from this efficient distributed system. The adoption of a Multi-Agent architecture responds to requirements prescribed by international boards and local governments; differently from cloud computing solutions that propose to centralize data in the cloud, MAS are more suitable to respect the distributed and federated nature of healthcare services. The proposed architecture ensures that clinical data are stored in the same place where they are produced, and seems better fit what prescribed by privacy laws. Furthermore legacy systems can be integrated simply wrapping them with agents that have to share the same ontology used by existing agents.

As future work the inclusion of proactive agents within the architecture will be investigated, mapping out possible improvements deriving from the adoption of goal-oriented behaviours with respect to the interoperability issue.

References

[1] U. Varshney, "Pervasive healthcare," *Computer*, vol. 36, no. 12, pp. 138–140, 2003.

[2] T. Kleinberger, M. Becker, E. Ras, A. Holzinger, and P. Müller, "Ambient intelligence in assisted living: enable elderly people to handle future interfaces," in *Universal access in human-computer interaction. Ambient interaction*. Springer, 2007, pp. 103–112.

[3] J. S. Ash, M. Berg, and E. Coiera, "Some unintended consequences of information technology in health care: the nature of patient care information system-related errors," *Journal of the American Medical Informatics Association : JAMIA*, vol. 11, no. 2, pp. 104–12, 2004.

[4] D. A. Ludwick and J. Doucette, "Adopting electronic medical records in primary care: lessons learned from health information systems implementation experience in seven countries," *International journal of medical informatics*, vol. 78, no. 1, pp. 22–31, 2009.

[5] R. Haux, "Health information systems - past, present, future." *International journal of medical informatics*, vol. 75, no. 3-4, pp. 268–81, 2006.

[6] M. E. Frisse, K. B. Johnson, H. Nian, C. L. Davison, C. S. Gadd, K. M. Unertl, P. A. Turri, and Q. Chen, "The financial impact of health information exchange on emergency department care," *Journal of the American Medical Informatics Association*, vol. 19, no. 3, pp. 328–333, 2012.

[7] D. Blumenthal, "Stimulating the adoption of health information technology," *New England Journal of Medicine*, vol. 360, no. 15, pp. 1477–1479, 2009.

[8] P. Ferronato, S. Lotti, and D. Berardi, "Strategia architetturale per la Sanità Elettronica," Tech. Rep., 2006.

[9] P. Leitão, "Agent-based distributed manufacturing control: A state-of-the-art survey," *Engineering Applications of Artificial Intelligence*, vol. 22, no. 7, pp. 979 – 991, 2009.

[10] M. Wooldridge and N. R. Jennings, "Intelligent agents: Theory and practice," *Knowledge engineering review*, vol. 10, no. 2, pp. 115–152, 1995.

[11] J. Nealon and A. Moreno, “Agent-based applications in health care,” in *Applications of Software Agent Technology in the Health Care Domain*, ser. Whitestein Series in Software Agent Technologies and Autonomic Computing. Birkhuser Basel, 2003, pp. 3–18.

[12] C. Doukas, T. Pliakas, and I. Maglogiannis, “Mobile healthcare information management utilizing cloud computing and android os,” in *Engineering in Medicine and Biology Society (EMBC), 2010 Annual International Conference of the IEEE*, 2010, pp. 1037–1040.

[13] C. O. Rolim, F. L. Koch, C. B. Westphall, J. Werner, A. Fracalossi, and G. S. Salvador, “A Cloud Computing Solution for Patient’s Data Collection in Health Care Institutions,” in *2010 Second International Conference on eHealth, Telemedicine, and Social Medicine*, no. ii. IEEE, 2010, pp. 95–99.

[14] V. Koufi, F. Malamateniou, and G. Vassilacopoulos, “Building Interoperable Health Information Systems Using Agent and Workflow Technologies,” in *Medical Informatics in a United and Healthy Europe*, 2009, pp. 180–184.

[15] D. Capozzi and G. Lanzola, “An Agent-Based Architecture for Home Care Monitoring and Education of Chronic Patients,” in *2010 Complexity in Engineering*, vol. 9. IEEE, 2010, pp. 138–140.

[16] M. Lyell and X. Liu, “Software agent application to support the patient-at-home,” in *2012 International Conference on Collaboration Technologies and Systems (CTS)*. IEEE, 2012, pp. 97–103.

[17] M. T. Nguyen, P. Fuhrer, and J. Pasquier-Rocha, “Enhancing e-health information systems with agent technology,” *International journal of telemedicine and applications*, vol. 2009, 2009.

[18] R. Heeks, “Health information systems: failure, success and improvisation,” *International journal of medical informatics*, vol. 75, no. 2, pp. 125–37, 2006.

[19] M. B. Buntin, M. F. Burke, M. C. Hoaglin, and D. Blumenthal, “The benefits of health information technology: A review of the recent literature shows predominantly positive results,” *Health Affairs*, vol. 30, no. 3, pp. 464–471, 2011.

[20] D. M. Lopez and B. Blobel, “Architectural approaches for hl7-based health information systems implementation,” *Methods of Information in Medicine*, vol. 49, no. 2, p. 196, 2010.

[21] A. W. Kushniruk, D. W. Bates, M. Bainbridge, M. S. Househ, and E. M. Borycki, “National efforts to improve health information system safety in canada, the united states of america and england,” *International Journal of Medical Informatics*, vol. 82, no. 5, pp. 149 – 160, 2013.

[22] H. Takabi, J. Joshi, and G.-J. Ahn, “Security and privacy challenges in cloud computing environments,” *Security Privacy, IEEE*, vol. 8, no. 6, pp. 24–31, 2010.

[23] F. L. Bellifemine, G. Caire, and D. Greenwood, *Developing Multi-Agent Systems with JADE (Wiley Series in Agent Technology)*. Wiley, 2007.

[24] L. Palazzo, A. F. Dragoni, A. Claudi, and G. Dolcini, “A multi-agent approach for health information systems domain,” in *Proc. of the 1st Workshop on Artificial Intelligence and NetMedicine (NetMed)*, 2012.

[25] M. Ciampi, G. De Pietro, C. Esposito, M. Sicuranza, and P. Donzelli, “On federating Health Information Systems,” in *International Conference in Green and Ubiquitous Technology*, no. March 2001, 2012, pp. 139–143.

[26] Italian Health Ministry, “Specifiche tecniche per la creazione del ”Profilo Sanitario Sintetico” secondo lo standard HL7-CDA Rel. 2, Tavolo Permanente per la Sanità Elettronica,” Tech. Rep., 2010.

[27] W3C Working Group, “Web Services Architecture. W3C Working Group Note 11 February 2004,” 2004. [Online]. Available: http://www.w3.org/TR/2004/NOTE-ws-arch-20040211/