A Multi-Agent Architecture for Health Information Systems

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Abstract. The healthcare domain is wide and characterized by system and data herogeneity. To achieve high quality and efficiency standards, interoperability between different information systems is strongly required.

The aim of this paper is to propose an agent oriented architecture to address this kind of issues, which is compliant with the European Union (EU) guidelines and with requirements issued by the italian Ministry of Health. To validate and to show the capabilities of our system, we developed on such architecture a typical emergency-response scenario, where a first aid medical staff urgently needs to retrieve, through mobile devices, the Patient Summary (PS) of a citizen, which is part of his Electronic Health Record (EHR).

Keywords. Health Information Systems, Interoperability, Multi-Agent Systems, Patient Summary, EHR, HL7 CDA

1. 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. The healthcare budgets are shrinking in many countries, and healthcare facilities are under pressure to provide better services with less resources [1]. Health Information Systems (HIS) are at the heart of all these challenges. They can provide a better coordination among medical professionals and facilities, thus reducing the number and incidence of medical errors. In the same time, they can reduce healthcare costs and may provide a means to improve the management of hospitals [2]. Unfortunately, due to the inherent complexity of their application domain, HIS are fragmented in various systems that hardly make use of communication standars, process definition protocols and homogeneus data representations. Much of the research in this field is aimed to address these problems, and different solutions have been proposed during the last years.

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1.1. 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 [3], in which a mobile application based on an Android client enables the users to retreive remotely health information and images. In [4] 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 [5], where data and service interoperability is obtained through a distributed and agent-oriented system. Finally, [6] and [7] use the multi-agent system technology to support the home-care monitoring and treatment of patients.

1.2. 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 multi-agent systems (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).

1.3. Paper Structure

The rest of this paper is organized as follow: section 2 details the multi-agent system architecture; section 3 illustrates an implementation related to an emergency-response scenario; section 4 includes a discussion of the results and concludes the paper.

2. Infrastructure

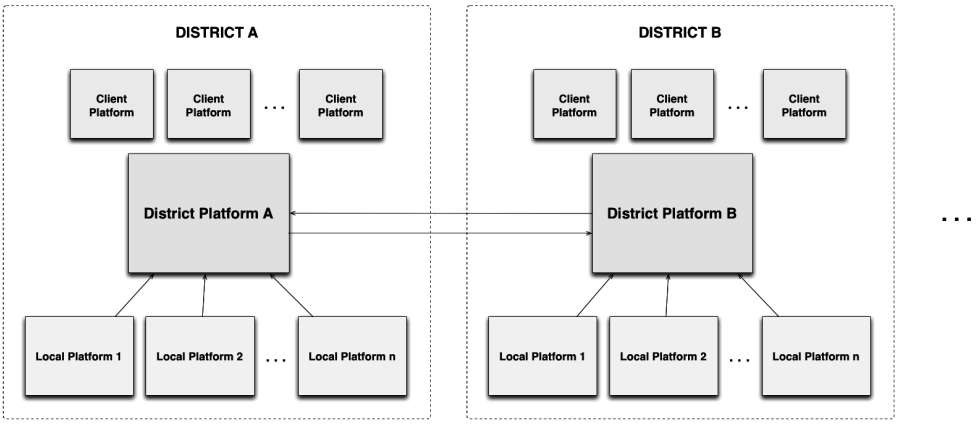

Figure 1. The global architecture is structured in three logic layers.

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 facilities in the territory (eg. 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.

2.1. Local Platform

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

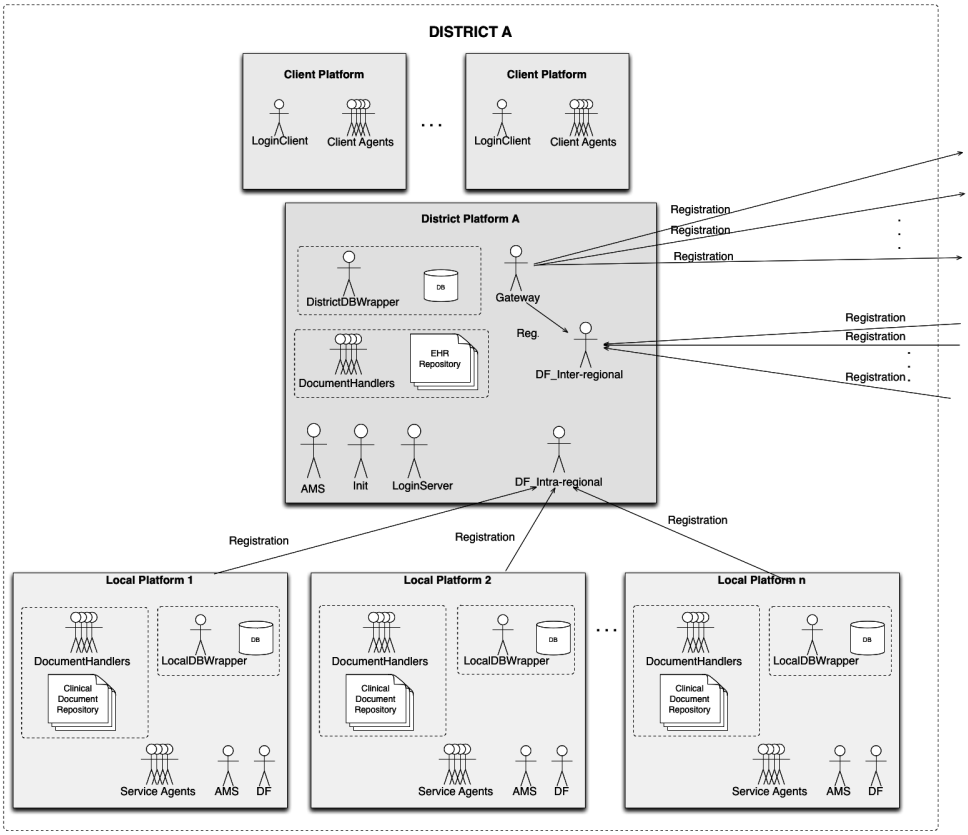

Figure 2. Relation between local platforms and their referring district platform.

onymy) 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.

In order to add a local platform to the entire agent oriented architecture, the LocalDB-Wrapper 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.

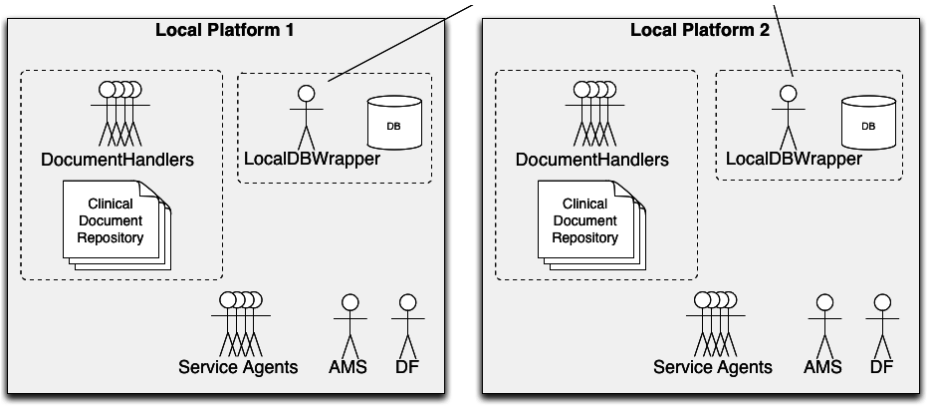

Figure 3. Local platform agents.

Service Agents.

This set consists of agents for the management of different departments of the health-care 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 [9].

2.2. District Platform

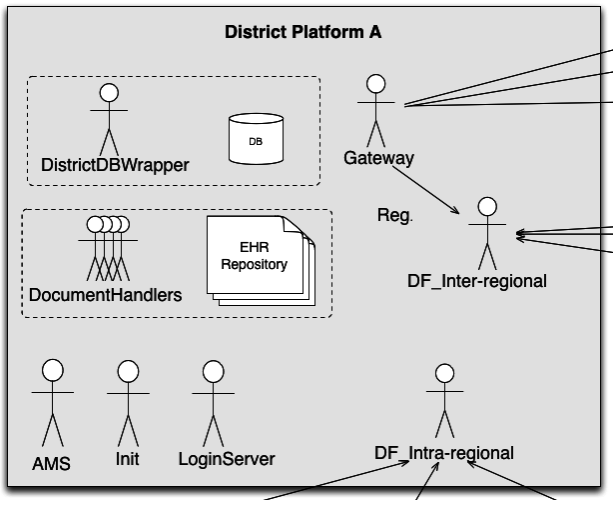

Figure 4. District platform agents.

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 discrict platforms, therefore, must know each other their address.

DistrictDBWrapper.

These agents has 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 EHR and Patient Summary [10]. 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 fulfill 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.

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 estabilish a secure connection with the client that wants to access to the infrastructure to retrieve data in a specified district.

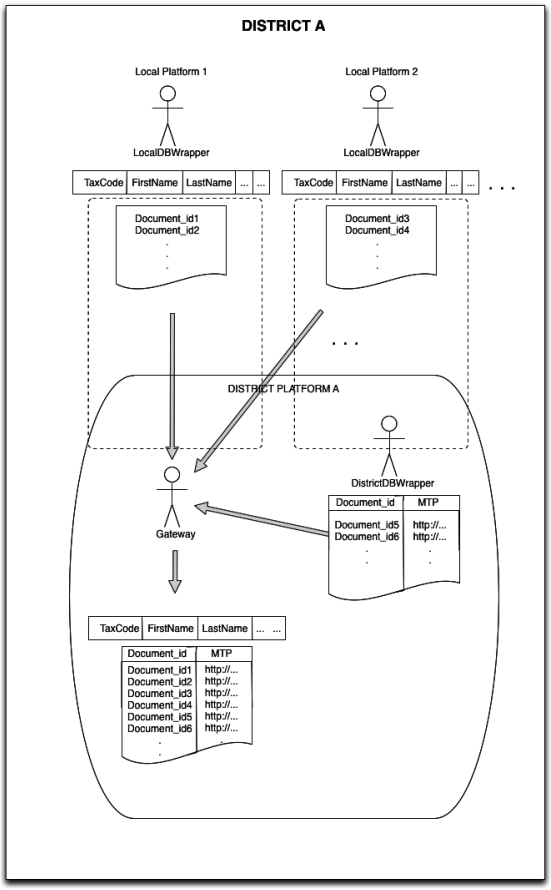

Figure 5. The Gateway agent retrieves the ubication of health records within the system.

2.3. Client Platform

This logic platform (Fig. 6) 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 Electronic Health Record (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.

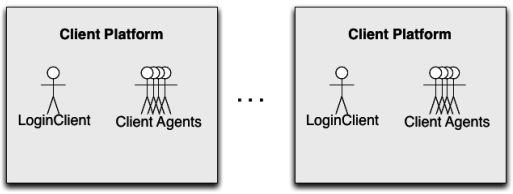

Figure 6. Client agents are any agent application that needs to access to the system.

3. Scenario

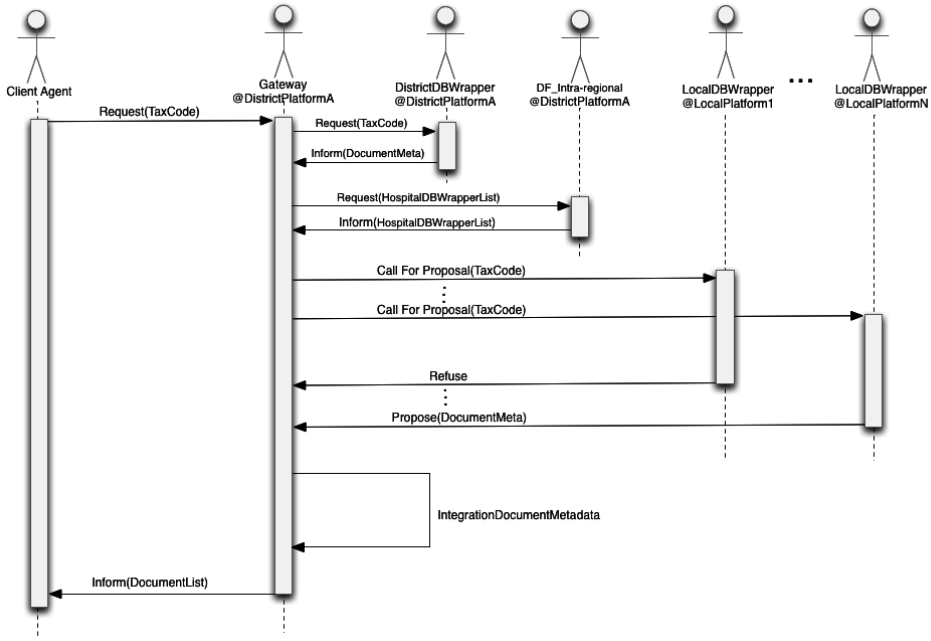

Figure 7. The client agent queries the infrastructure for a citizen's healthrecords.

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.

In short, the main Patient Summary's use cases can be summed up in [11]:

- 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 deseases 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 [12] to develop local and district agents in some desktop computers.

- An android smartphone application to simulate the client agent, developed with Jade Leap addon.
- 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 ubication 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.

4. 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 multi-agent systems 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 improve HIS in terms of interoperability, reliability, modularity and robustness; and how health professionals - and thus citizens - could benefit from this efficient distributed system.

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