Building Interoperable Health Information Systems Using Agent and Workflow Technologies

Vassiliki KOUFI¹, Flora MALAMATENIOU, George VASSILACOPOULOS

Department of Digital Systems, University of Piraeus, Greece

Abstract. Healthcare is an increasingly collaborative enterprise involving many individuals and organizations that coordinate their efforts toward promoting quality and efficient delivery of healthcare through the use of interoperable healthcare information systems. This paper presents a mediator-based approach for achieving data and service interoperability among disparate and geographically dispersed healthcare information systems. The proposed system architecture enables decoupling of the client applications and the server-side implementations while it ensures security in all transactions. It is a distributed system architecture based on the agent-oriented paradigm for communication and life cycle management while interactions are described according to the workflow metaphor. Thus robustness, high flexibility and fault tolerance are provided in an environment as dynamic and heterogeneous as healthcare.

Keywords. interoperable health information systems, mediator, software agents, workflows, WADE

1. Introduction

Healthcare delivery involves a broad range of in-patient, out-patient and emergency healthcare services, typically performed by a number of geographically distributed and organizationally disparate healthcare providers requiring increased collaboration and coordination of their activities in order to provide shared and integrated care when and where needed [1]. As healthcare providers are mostly hosting diverse information systems, promoting quality and efficient delivery of healthcare requires the use of interoperable healthcare information systems (HISs). The movement towards such a HIS requires an architecture that implements interoperability among existing information systems in all levels including service and data levels. Thus, collaboration among healthcare services is realized and patient information which is scattered around disparate and geographically dispersed systems can be readily accessed by authorized users at the point of care.

During the last few years, research efforts regarding the realization of interoperability among the existing HISs have been on the rise [2–11]. Technologies used for this purpose range from low-level techniques such as RPC/RMI to provider-
independent techniques based on XML/web services. These techniques have solved to a great extent the problem of interoperability of heterogeneous distributed systems but still lack the efficiency when it comes to performance issues. Moreover, the “Integrating the Healthcare Enterprises (IHE)” initiative profiles make a major contribution to interoperability issues regarding data and services but arise new problems due to lack of flexibility for adoption to different organizational conditions and lack of security integration in its different profiles [12].

This paper presents a, compatible to the EN 12967 standard [13], mediator-based system architecture that addresses HIS interoperability issues while it complies with the most stringent requirements of high performance, reliability, robustness, scalability, high flexibility and fault tolerance. To this end, the proposed system architecture utilizes both workflow and agent technologies. In particular, it uses a set of cooperating agents for the management of interactions between the client applications and the server-side implementations. Moreover, Java-based workflows are used for modeling both the logics of interactions and the internal behavior of each participating system. These workflows may involve several tasks such as data retrieval and transformation, computations and other low level auxiliary operations needed during execution of a process handling a client request.

2. Agent and Workflow Technology for Supporting Interoperability of Health Information Systems

Health information systems interoperability is a recent challenge aiming at reducing information cost while meeting the most stringent requirements of high performance, reliability, robustness, scalability, high flexibility and fault tolerance [14]. Effective management of interactions in such a heterogeneous and distributed environment is a fairly complex task. The conjunction of agent and workflow technologies provides the ability to execute such complex tasks and helps managing the complexity of the distribution in terms of both administration and fault tolerance. Hence, it can offer great benefits to the development of interoperable health information systems. When building such systems, data privacy and security are issues of paramount importance and need to be addressed. Thus, appropriate safeguards of a technical nature should be used to secure personal information against unauthorized access, collection, use, disclosure or disposal.

Workflows and Agents Development Environment (WADE), which is the main evolution of Java Agent Development Environment (JADE) [15], is a software platform suitable for the development of mission critical applications by exploiting agent and workflow technologies [16]. In particular, it facilitates the development of interoperable multi-agent systems where agent tasks can be defined according to the workflow metaphor. In WADE each workflow is expressed as a Java class with a well defined structure, thus combining the advantages of workflow technology with the power and flexibility of an actual programming language like Java. Unlike the majority of existing workflow systems that provide a powerful centralized engine, in WADE each agent can embed a “micro workflow engine” and a complex process can be carried out by a set of cooperating agents each one executing a piece of the process [16]. This improves significantly performance which is a matter of prominent importance in the healthcare field.
3. Motivating Scenario

The basic motivation for this research stems from our involvement in a recent project concerned with defining and automating cross-organizational healthcare processes spanning a health district in order to implement a district-wide, process-oriented health information system. The interoperability requirements and the stringent needs for a secure, reliable and high performance system that provides real-time access to sensitive patient information motivated this work and provided some of the background supportive information for developing the prototype presented in this paper.

Typically, a health district consists of one district general hospital (DGH) and a number of peripheral hospitals and health centers. As patient information is scattered around disparate and geographically dispersed systems and patient referrals are usually made among various healthcare providers within a district (e.g., for hospitalization, for outpatient consultation or for performing specialized medical procedures), there is a need to ensure that a high performance interoperable environment is created and that authorized access to healthcare services and data is provided.

4. System Architecture

Figure 1 illustrates a high-level view of the system architecture in terms of a three-tier model which comprises the PDA client, the mediator and the health district information systems. The latter are, in general, heterogeneous and reside in geographically distributed and organizationally disparate healthcare providers within the health district. The mediator lies between the client and the health district information systems.

In essence, the mediator is a distributed, multi-agent system that enables client interactions with the existing information systems. Mediator agents are built using the WADE platform and are held in containers which run on various servers that reside at the DGH and other peripheral sites within the boundaries of the health district. In each server, containers are activated by a BootDaemon process and container agents are then employed to process access requests to information systems and to decide whether each request should be permitted or denied. This access control process, that involves the execution of a number of agent tasks, has been defined according to the workflow metaphor.

One of the two containers hosted at the DGH site is called the main container while the rest of the containers, hosted at the DGH site and elsewhere, are called peripheral. The main container holds the WADE-specific agents (i.e., the Agent Management System (AMS), the Directory Facilitator (DF) and the Configuration Agent (CFA)) [15] and one application-specific agent, namely the Gateway Agent (GA), which enables the communication between the client portal and the mediator. Each peripheral container holds a WADE-specific agent, namely Controller Agent (CA) [15], and two application-specific agents, namely Information System Agent (ISA) and Access Control Agent (ACA).

ISA is the core component of the mediator. On arrival of an access request to an information system of a healthcare organization site, the local ISA handles the request in collaboration with the local ACA which enforces access control. Thus, ISA provides a standard interface to the underlying database(s) and applications, facilitating interoperability in terms of service accessibility and data semantics. Moreover, the ISA hosted at the DGH peripheral container handles interactions among the various interoperable information systems operating within the health district. For example,
upon request concerning the retrieval of a portion of a patient’s medical record, the DGH ISA locates the various pieces of the requested information using a district-wide directory and commands the relevant ISAs to retrieve and deliver the requested pieces of information to the DGH ISA.

The low level internal structures of the application-specific agents and the high level interactions between agents and the DGH ISA are modeled as workflows. Hence, all agents are designed to include a light workflow engine that executes these workflows. The workflows modeling the low level internal structures of the each ISA are executed by the workflow engine embedded in it and involve, among others, tasks such as data retrieval and transformation (including computations and other low level auxiliary operations) in accordance to the reference information model defined by the EN 12967 standard. Thus, semantic interoperability can be realized. Each time a modification occurs in the database(s) and/or applications of a health information system a new or modified workflow reflecting the modification can be deployed at runtime, thus immediately enabling the local ISA to access it. The workflows modeling the high level interactions between agents and the DGH ISA are executed by the workflow engine embedded in the DGH ISA and involve, among others, tasks such as the integration of the portions of a patient’s medical record delivered to it by ISAs.

In the proposed architecture, authorization decisions are taken by ACA which, during a user interaction with the system, determines whether access of a given subject (healthcare professional) to given object (healthcare service or data) should be permitted or denied by taking into account the current context. The contextual information influencing authorization decisions is determined by a pre-defined set of attributes that may relate to the user (e.g., user roles, user/patient relationship), to the environment (e.g., client location and time of attempted access) and to the data resource provider (e.g., the healthcare organization’s security policy). For example, the permissions of a physician accessing the system via his/her PDA, are adapted depending on his/her identity, location and time of access as well as the security policy of each healthcare organization where a portion of the requested information is stored. The whole access control process performed by ACA in order to ensure authorized access to the target objects is also modeled as a workflow process.

5. Implementation Issues

A prototype based on the architecture presented in this paper has been developed in a laboratory environment using WADE 2.0. The latter is built on top of JADE [15] and uses Java Runtime Environment 1.5.0 for executing the workflows that define agent tasks. Due to lack of space, a comprehensive description of the prototype implementation is not provided here.

6. Concluding Remarks

Healthcare organizations are faced with the challenge to reduce cost and improve quality of the services they provide. In this context, rendering existing information systems interoperable is of paramount importance. Healthcare professionals often require instant access to accurate patient information which may be scattered around disparate and geographically dispersed systems. Thus, when building an interoperable
health information system there is a need to ensure that the most stringent requirements of high performance, reliability, security, robustness, scalability, high flexibility and fault tolerance are met. To this end, the proposed system architecture implements a workflow-based mediation framework, built on agent technology, to provide an interoperable healthcare information system environment that enables integrated and secure access to medical information irrespective of the location it resides.

References


