A Conceptual Framework for Ubiquitously Sharing Heterogeneous *Patient Information among* Autonomous H*ealthcare Providers*

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Abstract - *Ubiquity has been a key element to modern medical diagnosis system to improve medical service's efficiency and convenience on both medical personals and patients' sides. Mobile agents and peer-to-peer technologies make this anticipation possible. This paper proposes a framework to ubiquitously share patient medical information among geographically distributed healthcare providers. The proposed approach is based on ontologies, mobile agents and peer-to-peer technology for bringing together autonomous heterogeneous and highly distributed health care facilities.*

Keywords: Medical Information System, Ontology, Peer-to-Peer, Multi-agent

1. Introduction

Over the last few years, there has been a shift from administrative health systems that are concerned primarily with billing procedures to clinical information systems that provide support for providers of health care. Clinical information that is universally available is a key to reliable patient care and reliable medical systems. The possibility of sharing a complete profile of a patient that is conveniently analyzed can improve significantly the healthcare services, reducing cost and improving efficiency and safety of the patients [4].

However, sharing electronic patient records both in a single medical institution and across healthcare institute boundaries is difficult if not imposable [4]. There are many factors contributing to this problem. First, health information systems are inherently distributed and autonomously managed. The problem is further exacerbated by improvement of people's living standard and increasing mobility of people's activities. The proprietary nature of the systems has also contributed to the heterogeneous formats used to store the data and access methods and procedures as well as to the lack of inter-operability among the information repositories of such data sets. Also, there are legal and ethical issues that influence sharing of patient information.

As communication between doctors becomes more significant and the response to the clinical inquiry is becoming the key issue, the access of data anywhere/anytime in a clinical environment is considered an important aspect of quality of care. Therefore, with improvement of people's living standard and increasing mobility of people's activities, an effective and ubiquitous healthcare system for both doctors and patients is a must.

This paper proposes a general conceptual model for search and access to clinical information across healthcare enterprises. The proposed model is based on three technologies: peer-to-peer (P2P), mobile agents and ontology. The aim of this framework is to provide a ubiquitous and interactive medical care system to assist medical doctors' in optimal decision making, thus improving the medical system's availability to the public. To this end, we propose a novel ontology-based software agent and peer-to-peer (P2P) networking paradigm to provide a flexible and dynamic conglomeration of data across any combination of the

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participating heterogeneous data sources to maximize knowledge sharing.

The rest of the paper is organized as follows. In Section 2, we discuss related work. In Section 3, we present a conceptual model for bringing together autonomous heterogeneous and highly distributed health care facilities. In Section 4, we present an example of the usage. The conclusions and future directions are presented in Section 5.

2. Related Work

Currently, a patient's health information may be spread out over a number of different healthcare providers that do not interoperate, which makes it very difficult for clinicians to capture a complete clinical history of a patient. The general problem we are trying to solve is how to accelerate the appropriate use of information technology to provide useful support for access to medical information for clinical care, research, teaching, health services administration and patient care.

As most of the health information systems are proprietary and often only serve one specific department within a healthcare institute [3], search and access to clinical information across healthcare enterprises is quite hard if not impossible.

The multi-agent paradigm has been successfully applied to a variety of scenarios where applications are inherently distributed [4]. For example, a Multi-Agent based Medical Information System (MAMIS) is discussed in [4]. MAMIS is based on the assumption that a healthcare provider keeps 2 a private databases and a public databases where the later is used for sharing. It also assumes that the database is homogenous.

We propose the use of ontology [1] to address the problem of interoperability of healthcare information system. Ontology is a data model that represents a domain and is used to reason about the objects in that domain and the relations between them.

Current ontological approaches to the merging of heterogeneous data have been successful, but require the owners of the data to participate in the adoption of a single common ontology. An approach that uses that uses semantically enriched web service based on prominent healthcare standards as references to facilitate semantic mediation among involved institutes is discussed in [3]. The focus of this work is on interoperability issues, which is only one dimension of the current problem.

In our approach, we use P2P technology to couple the healthcare domains. In the past few years, P2P applications have emerged as a popular way of sharing data in decentralized and distributed environments. P2P data management systems (PDMS) [6, 7] have emerged as a more flexible solution for scalable data sharing, where every PDMS peer can join easily the sharing environment and contribute new data. For example Hyperion project [5] uses P2P to address the problem at hand. However, all peer nodes are assumed to have identical architectures, which makes it unsuitable for heterogeneous environments that is most likely the case of the current healthcare information system.

3. Conceptual Model

In this section, we present the conceptual framework of the virtual medical information systems. We also describe the main components and their functionality.

3.1 Virtual Healthcare System

Figure 1 shows the virtual medical information system architecture. The goal is to provide a solution for patient information search on a community of autonomous healthcare units and provide ubiquitous information access to physicians and healthcare professionals in a variety of situations. Towards this objective, the proposed virtual healthcare framework decisively marries ontology-based agent paradigm and P2P network technologies for the retrieval of information residing in healthcare information systems.

There are $P = \{P_1, P_2, \cdots, P_N\}$ data sources called peers, which participate in data sharing by clustering themselves into interest groups and establishing pair-wise associates between them. Peer-to-peer (P2P) architectures allow for loosely coupled integration of information services while agents will enable sharing of information transparently. Moreover, P2P communication architecture provides scalability and facilitates the discovery of other mediators.

In this paper, it is assumed that there are differences in the way patients' information is represented both at the schema and at the data instance level in the peer databases. Each healthcare provider operates autonomously within peer group. Peers can join or leave the network at their own discretion. Moreover, a peer may form an *associate* with another peer, for data sharing purposes. When peers become acquainted, local ontologies necessary to allow data sharing are exchange automatically. Note that each healthcare provider containing medical information is autonomous and controls entirely its data. This model preserves the independence of the different healthcare providers while at the same time creates the possibility for sharing of medical information.

Sharing medical information between different healthcare provides has the potential to work because both sides of the partnership benefit. However, since these providers handle extremely important private data (e.g. a patient's health data) they may be reluctant to share their problems, data, etc. This fear is mitigated by using certificates to request and encrypt messages between the agenst. Certificate Authority (CA) issues a certificate to subjects and provides system validation and authentication functions to users and devices.

In the following subsections, we will discuss the components of the virtual healthcare system shown in Figure 1.

3.2 Mobile-Agents

All the interaction between the peers in the system occur trough agents. Agents are programs that can migrate from host to host in a network, at times and to places of their own choosing. Mobile agents have the advantages on reducing network load and overcoming network latency. They can encapsulate protocols, work remotely, asynchronously and even disconnected from a network. Also, a great number of agent platforms are deployed for accessing databases.

We use an agent for each data set maintained by a given peer. The agents resides on the doctor's computer (desktop or portable computer) and are empowered to search for information, retrieving data from the underlying data repository as well as presents the data to the overall system for merging, and provide the ability to dynamically form composite ontologies from the metadata sources. In this way, the cost of developing these ontologies is reduced while providing the broadest possible access to available data sources.

3.3 Sharing Policy

Agent societies are formed when agents with similar interests come together to work towards a common goal. This implies that these agents in a society should adhere to the rules laid down by the society. These rules or protocols should be transmitted in a secure way. There might be a malicious agent,

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which might want to break the rules of the society or may want to send a false protocol to the other agents in the society. This gives rise to a security protocol for interactions among the agent societies. There are many approaches that could be integrated in the agent system that will be discussed in the extended version of the paper.

3.4 Developing the Ontology

Since medical information systems today store clinical information about patients in all kinds of proprietary formats, this leads to the interoperability problem. In Figure 1, please note that there are differences in the way patients' information is represented both at the schema and at the data instance level in the databases. This representational discrepancy raises the need for some way of mapping one schema to another. To address this problem, we use ontologies.

We use two types of ontolgies: *Local ontology* and *Composite ontology*. Local ontology indexes data concepts with their contextual aspects in form of properties according to their domain of application. It is assumed that local ontology is built by the data owners (i.e., health providers). Local ontology is composed of *local data concepts* and *master data concepts* as shown in Figure 1. We used a simple system that specifies data concepts by defining the equivalence relations between a data owner's local data concepts and other participating data concepts. For example, as shown in Figure 2, the data set of the *Dire Clinic* provides a simple list of data elements. The first column is labelled *Local* and the second column is labelled *Master*. Together they represent a simple ontology, i.e., a specification of the data concepts represented by a mapping from the *Local* to the *Master data concept list*. Next we incorporate data from *Wassim Hospital* in the same manner as just described.

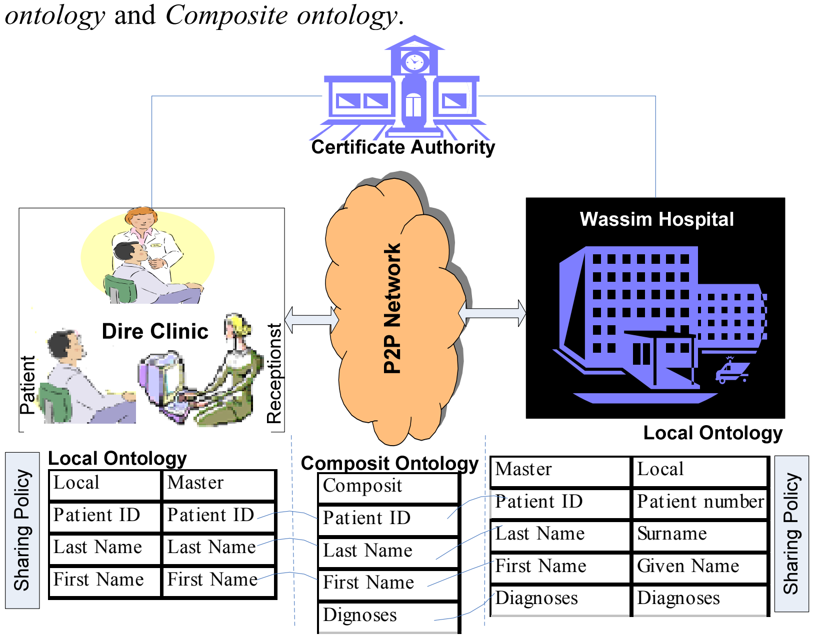

Figure 1: Conceptual model for virtual healthcare infrastructure

In contrast, the *composite ontology* is a union of the data concepts across all participating data sets, and a given data set's ontology is a mapping specifying the relationships between the intersection of that data set's local data concepts and the master data concepts. In order to construct

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composite ontologies for *Wassim Clinic* data set, the data agent looked at *Dire Clinic's* ontology mapping. Each data concept in a local data list was mapped to the same concept in the *Master*. If Wassim Clinic had data that was not in the *Master*, a new entry was added to the *Master*. Conversely, if a data concept in the *Master* was not present in the local ontology then there was no mapping established from *Wassim Clinic's Local* to the *Master*. In the end, the system consists of three ontologies: (1) composite, (2) Dire *Local Ontology*, and (3) Wassim Clinic *Local Ontology*. This process continues for each new data set. Each new data owner uses the previous work to help determine their ontology as a specification of the mapping from their *Local* to the *Master data concepts list*.

Relationships among a selection of the local data sets' ontologies can be determined using the omposite ontology as a point of common reference. It is interesting to note that ontology for the entire system is distributed across the ontology mappings of the individual data sets and the *Master*. For example, Dire Clinic d*ata set* "Last Name" specifies the same concept as Wassim Hospital d*ata set* "Surname" but this cannot be directly determined at one centralized point; rather it is determined via the data set ontologies and the *composit ontology*.

In the conceptual model shown in Figure 1, every medical information system is represented as an autonomous peer. Peers belong to *interest groups*, such as physicians or medical laboratories. When peers become acquainted, logical metadata necessary to allow data sharing are exchanged automatically. These metadata take the form of mappings, both at the data level and schema level, and they help to bridge semantic and syntactic heterogeneities between peers.

Note that peers are not obliged to adhere strictly to a globally agreed ontology provided by a central mediator (the bottleneck of the centralized integration systems); rather they could develop their own local ontologies. The only requirement is that they must relate their local ontologies'concepts to those belonging to their neighbors.

Data sharing is achieved by initiating a request for the data through the local agent. The agents use distributed local ontology and composite ontology to provide the functionality of a centralized ontology along with the ability to be flexible in meeting the varied needs of the users.

To use the system, a doctor first brings up the GUI and invokes the local data agent (LDA) for a list of available agents in the peer group. The LDA then checks the list of agents that are registered, and verifies the availability of each. This agent then reports the availability to the GUI Agent, who displays the available data sources to the user. The user then selects the desired data sources and the software agents dynamically create a merged ontology for the selected data sources. To create this merged ontology, the agent sequentially distributes the *Master* concepts to the LDA chosen by the user. The first DA compares this concept list to his local ontology, and deletes from this list the data concepts that are not found (i.e., the data concepts that are not in the local ontology). The LDAs then hands the reduced data concept list back to the requesting LDA who then passes the reduced list to the next LDA selected by the user. This process continues for each of the user-selected agents until all have seen the list. The final reduced data concepts list, in conjunction with each participating data agent's ontology, constitutes a shared ontology across the participating data sets. This ontology is dynamically generated based on a request from a user, and is evaluated against the latest information from each local data source.

Participating agents can each understand and provide information about all the data concepts that are shared across the participating systems, which significantly increase the capability of current ontologies producing results in much the same way a group of collaborating humans would have done, but significantly faster, and with far greater accuracy.

4 Conclusions and Future Directions

In this paper, we proposed a novel ontology-based software agent and peer-to-peer (P2P) networking paradigm to provide a flexible and dynamic conglomeration of data across any combination of the participating heterogeneous data sources to maximize knowledge sharing. For example, this will allow a family physician to find the results of any lab tests stored in the database of any acquainted specialist physician, pharmacy or medical laboratory. The proposed approach provides a more flexible solution for scalable data sharing, where every PDMS peer can join easily the sharing environment and contribute new data, then relate them to existing neighbors' local ontologies, define itself a new local ontology that others can use as a glue to relate their own ontologies to the rest of the network.

We envision building ontologies by using clustering techniques; new data concepts would naturally cluster close to matching data concepts that have already been incorporated. Also, P2P platform is very risky, because it makes you very susceptible to infection, attack, exposure of personal or company information. Therefore, techniques to mitigate these problems will be investigated.

That ontology mapping allows the data agent to act in a bilingual manner (i.e., understand both the local and composite concepts). Based on the master data concepts side of the ontology, the agent understands the language of the agent community; based on the local data concepts side of the ontology, the agent understands how to retrieve the local data; and based on the mapping between the two sides of the ontology, the agent understands how to translate between the two.

5 References

1. Chandrasekaran, B., Josephson, J.R. and Benjamin V.R., What are Ontologies, and Why Do We Need Them?, IEEE Intelligent Systems, Volume 14, No.1; January/February 1999, 20-26
2. Gruber, T., A Translation Approach to Portable Ontology Specifications, Knowledge Acquisition, 5(2), 199-220, 1993
3. Dogac, A., Laleci, G., Kirbas S., Kabak Y., Sinir S., Yildiz A., Gurcan Y., Artemis: Deploying Semantically Enriched Web Services in the Healthcare Domain, Information Systems Journal.
4. José Manuel Fonseca André Damas Mora Ana Celeste Marques, A Multiagent Information System for Bioprofile Collection, Proceedings of CIMED'05, 2005.
5. M. Arenas, V. Kantere, A. Kementsietsidis, I. Kiringa, R. Miller and J. Mylopoulos. The Hyperion Project: from Data Integration to Data Coordination. In SIGMOD Record 32(3), 2003.
6. K. Aberer, P. Cudr´e-Mauroux, and M. Hauswirth. Message-passing in peer data management systems, 2006.
7. A. Y. Halevy, Z. G. Ives, D. Suciu, and I. Tatarinov. Schema mediation in peer data management systems. In ICDE, pages 505–, 2003.

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