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An Intelligent Agent-based Knowledge Broker for Enterprise-wide Healthcare Knowledge Procurement

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Abstract

Within the confines of a Healthcare Enterprise Memory (HEM), most traditional medical systems do not sufficiently provide the necessary assistance to healthcare practitioners in the handling of critical situations. Furthermore, localized knowledge repositories are often lacking the required knowledge for problem solving. Therefore, in this paper, we present an agent-based knowledge broker called the Intelligent Healthcare Knowledge Assistant (IHKA) for dynamic knowledge gathering, filtering, adaptation and acquisition from a HEM comprising an amalgamation of (i) databases storing empirical knowledge, (ii) case-bases storing experiential knowledge, (iii) scenario-bases storing tacit knowledge and (iv) document-bases storing explicit knowledge. The featured work leverages intelligent agent techniques for autonomous HEM-wide navigation, approximate content matching, inter- and intra-repositories content correlation, and knowledge adaptation and procurement to meet the user's healthcare knowledge needs.

1. Introduction

The transformation of healthcare intuitions to sophisticated computerized environments has resulted in the generation and transaction of volumes of healthcare information and knowledge for routine healthcare activities. Notwithstanding issues pertaining to the storage of volumes of healthcare information, there is an imminent need to address issues regarding effective information/knowledge utilization and management. To meet this end, lately a number of Healthcare Enterprise/Organizational Memories (HEM) have been developed to manage, ontologically classify and store the different types of healthcare knowledge in functionally divergent repositories within the unified HEM framework [1][2]. Vis-à-vis healthcare knowledge management via the implementation of HEM, we note that two problems tend to persist: (i) most medical knowledge-based systems, although built with the aim of delivering accurate and timely results, are often suitable only to address non-critical healthcare situations. These do not command the trust to handle critical healthcare problems; and (ii) the knowledge within a local HEM may not be sufficient to address the required knowledge needs of its users.

In this paper, we present an agent-based solution to the above constraints via the implementation of an agent-based knowledge broker called the *Intelligent Healthcare Knowledge Assistant (IHKA)*. IHKA is a client-server info-structure that features autonomous knowledge gathering, filtering, adaptation and acquisition from a HEM comprising an amalgamation of (i) databases storing empirical knowledge, (ii) case-bases storing experiential knowledge [3], (iii) scenario-bases storing tacit knowledge [4] and (iv) document-bases storing explicit knowledge. Simply put, in contrast to traditional experts systems that provide solutions, the IHKA provides assistance, thus, making it more suitable for assisting a non-expert healthcare practitioner in critical situations. Functionally, given a knowledge retrieval specification, the IHKA provides the user with relevant and focused knowledge via (a) *autonomous HEM-wide navigation*; (b) *autonomous Internet-wide healthcare knowledge procurement*; (c) *approximate matching* of user's knowledge specification with HEM contents; (d) *content correlation* involving the creation of content similarity links between inter- and intra-repositories; and (e) *knowledge adaptation* involving the modification of HEM-specific knowledge to optimally meet the user's knowledge request. Figure 1, illustrates the functionality of IHKA.

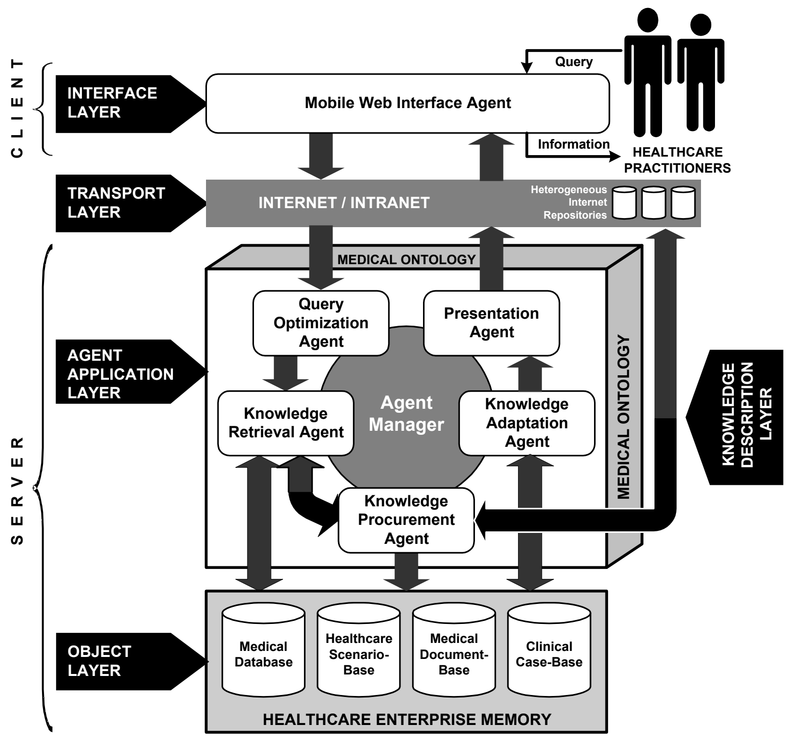

Figure 1. Intelligent healthcare knowledge assistant functional overview

2. Agent-based intelligent healthcare knowledge assistant: An overview

In our work, we explore the possibility of leveraging intelligent agents in a healthcare context. Intelligent agents can be viewed as autonomous software (or hardware) constructs that are proactively involved in achieving a predetermined task and at the same time reacting to its environment. Intelligent agents also social entities where they can communicate with other agents using an agent-communication language (such as the *Knowledge Query Manipulation Language* (KQML)) in the process of carrying out their tasks [5][6].

IHKA is a framework consisting of: (a) a HEM—a *healthcare knowledge web*—which provides access paths to diverse knowledge sources; and (b) agent-mediated intelligent access to, and procurement of, heterogeneous knowledge by approximate matching of resources, content navigation, and content correlation. IHKA's focused knowledge search and navigation is grounded in five fundamental principles: (i) it employs specific functionally-autonomous knowledge retrieval and procurement agents for each constituent repository; (ii) it employs a common ontology modeling the knowledge objects; (iii) it collects knowledge by leveraging a medical ontology that assists knowledge matching and adaptation; (iv) it populates the HEM from *only* those sources that need to be accessed for relevant content; and (v) it ensures inter-agent communication for agent collaboration to traverse the HEM for 'holistic' knowledge retrieval.

Interaction with a HEM is facilitated by the IHKA, whereby the user's knowledge needs are specified as a *Knowledge Specification* (KS)—akin to a query. The inherent medical ontology allows for the expansion of the KS. For example, if a practitioner needs knowledge pertaining to treatment of chronic headaches in the frontal region, the query may comprise the following features or ontological terms: **condition:** [headache, head pain, ache, pains in head]; **duration:** [chronic, long time, several months]; **location:** [frontal, forehead, front of head]; and **task**: [diagnostic support, diagnosis]. Based on such a KS, the IHKA will activate the intelligent agents to retrieve specific knowledge from the constituent repositories—i.e. the database, case-base, scenario-base and the document-base, or to initiate a knowledge procurement exercise from external resources. Knowledge retrieved from the different sources will provide different perspective to the user, for instance the case-base may provide experiential diagnostic-support, the scenario-base may reflect on the tacit knowledge of domain experts and the document base may provide texts and notes, etc. The resulting knowledge package is therefore expected to be 'holistic', and more attractively it has been retrieved by a simple generic query to the HEM.

The operational workflow of IHKA has been characterized by an agent-based framework comprising six independent agents:

1. *Mobile Web Interface Agent (MWIA)*: This agent establishes a web-based interface at the client side via the internet/intranet [7][8] and provides the functionality to receive KS from healthcare practitioners.
2. *Query Optimizing Agent (QOA)*: This agent accepts KS from the MWIA, and in turn recomposes the queries in line with the medical ontology and the inherent knowledge access protocols of the various HEM's repositories.
3. *Knowledge Retrieval Agent (KRA)*: This is the central intelligent agent and is responsible for the autonomous navigation, approximate matching, and content co-relation features of the IHKA. Based on the optimized query from the QOA, this agent retrieves the relevant knowledge from the HEM.
4. *Knowledge Adaptation Agent (KAA)*: In case the retrieved knowledge (by the KRA) is not in line with the user's specification then the KAA can be invoked to operate on the available knowledge and the content correlation links to adapt the retrieved knowledge in order to yield an optimum response.
5. *Knowledge Procurement Agent (KPA)*: In the event the KRA is unable to retrieve the desired results from the HEM's internal repositories, the KPA searches the internet, acquires and adapts the required knowledge for the purpose of fulfilling the queries and enriching the HEM's repositories.
6. *Presentation Agent (PA)*: This agent prepares and formats the search results to be presented to the user via the MWIA. The results are presented in an intuitive manner so as to allow the healthcare practitioner to make informed decisions.

3. Agent-based healthcare knowledge retrieval and adaptation

Here, we highlight three key agents of the IHKA and discuss their tasks in more detail.

3.1. Knowledge retrieval agent

At the heart of the KRA is the retrieval manager. In view that the HEM consists of four different storage formats (i.e. databases, case-bases, scenario-bases and document-bases), the retrieval manager manages four broker agents. The retrieval manager obtains the optimized queries from the QOA and passes the specialized queries to the respective broker agents. These broker agents are then dispatched and will eventually report to the retrieval manager with the results. Figure 2 illustrates the retrieval agent and its components.

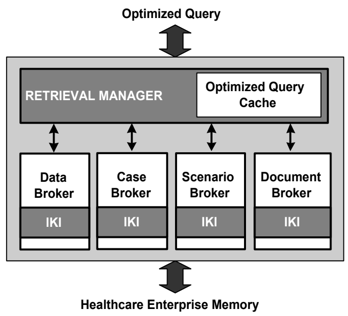

Figure 2. Knowledge retrieval agent

DOMAIN	CLASS	SUB-CLASS	VECTOR = S1, S2, S3, ..., Sn	CASE #
Health	Cardiology	Cardiac arrest	Heart failure, Bleeding, Vein blockage	Case 6
Health	Cardiology	Cardiac arrest	Heart failure, Bleeding, Valve blockage	Case 4
Health	Liver	Liver failure	Bleeding, Liver failure, Vein blockage	Case 3
Health	Cardiology	Cardiac arrest	Heart failure, Liver failure, Vein blockage	Case 2
			Sn!, Sn2, Sn3, ..., Snn	Case n

VECTORS

Figure 3. Inverted knowledge index of an exemplar case-base

The optimized query cache (OQC), which is part of the retrieval manager, keeps a record of optimized queries with pointers to specific data, cases, scenarios and documents that match the queries. When the retrieval manager receives a query, the OQC is verified to see if the same query was made in the past. Therefore, with frequent usage of the IHKA, the OQC will allow the retrieval manager to obtain results more efficiently by pinpointing relevant results without having to search through the entire HEM.

In the event that a query is not found in the OQC, the brokers will then be facilitated by the inverted knowledge indexes (IKI) [9] for the respective databases, case-bases (see Figure 3), scenario-bases and document-bases. These IKIs include vectors that contain keywords defining the properties, situations or content of a particular data, case, scenario or document. Each vector also includes a pointer to the respective data, case, scenario or document.

The internal generic structure of a KRA broker agent is shown in Figure 4. The Event Handler and Event Buffer serve to handle interactions and messages that are passed to and from the Retrieval Manager and other agents. The Event Handler basically manipulates a queue of events which are passed on to an Effector. The Effector then takes the appropriate action based on its Environmental Knowledge in response to a particular event.

A detailed description of all the various broker agents is beyond the scope of this paper. However, here, we will describe the functionalities of the case broker agent in more detail. The main task of the case broker agent is to obtain similarity measures for past cases with respect to the query (or query case). For our purpose, the similarity measure is represented by a Total Net Distance (TND) value calculated based on all its case fields. Before the TND can be calculated, the *Field Level Distance (FLD)* of each field needs to be obtained (where if a particular field, F_n, in the query case matches the corresponding F_n of a past case, this will produce a FLD value of 1; failure to match would yield a FLD value of 0). The formula to calculate the TND is as follows:

$$\text{Total Net Distance, } TND = TFD \times RFD$$

$$\text{where, Total Field Distance, } TFD = \frac{\sum_{1}^{|F|} FLD}{|F|},$$

$$\text{Relative Field Distance, } RFD = \frac{|F|_{query}}{|F|_{past}}, \text{ and}$$

$$|F| = \text{number of fields in a particular case.}$$

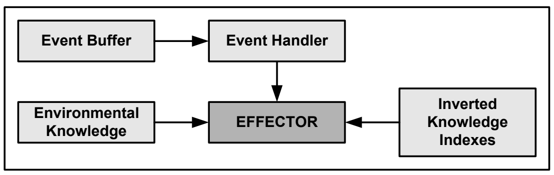

Figure 4. Generic structure of a broker agent within the knowledge retrieval agent

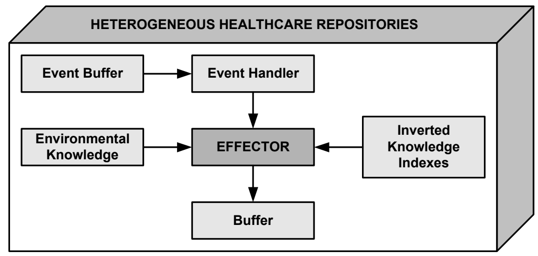

Figure 5. Generic structure of a broker agent within the knowledge procurement agent

3.2. Knowledge adaptation agent

In the context of our IHKA, the adaptation agent is more relevant to the retrieval of clinical cases and healthcare scenarios. The adaptation agent of the IHKA employs a case-based reasoning (CBR) technique called compositional adaptation [10][11]. For our purpose, we will be using a combination of horizontal and vertical compositional adaptation. The rationale for this choice is grounded on the fact that since the similarity between cases is determined at the level of the case fields, the best adapted solution should be obtained through the case field's similarity measure, i.e. TND, that is derived when comparing the query and past cases.

3.3. Knowledge procurement agent

The KPA typically takes over from the KRA in the event that the required results are not available internally and is actually very similar in design to the KRA. It also deploys four broker agents whose internal structure (see Figure 5) and functions are slightly different from those deployed in the KRA. The main objective of the KPA is to fetch related healthcare knowledge that is available externally across the internet from other healthcare enterprises. The KPA is able to connect to heterogeneous repositories and will utilize its Environmental Knowledge to evaluate and analyze the structure of the different repositories to facilitate the knowledge procurement process. A buffer component is used to store the procured content temporarily and some adaptation is carried out (if necessary) at the source of the knowledge.

4. Intelligent healthcare knowledge assistant info-structure

In putting everything together, we present a five-layer IHKA info-structure (see Figure 1 above). The five layers are highly specialized and yet interdependent to achieve the goal of providing intelligent healthcare assistance on demand. The info-structure provides a plug-and-play environment that will allow, in future, other components and agents to be added to further enhance the efficacy of the IHKA. The medical ontology, that is present at the knowledge description layer, serves as a defined taxonomy of healthcare knowledge and a standard healthcare vocabulary to achieve knowledge standardization [12]. This standardization facilitates the broker agents in their search through the HEM that could potentially contain data, cases, scenarios and documents with different terms for the same concept.

At the object layer, we have medical databases that contain data obtained from various studies or surveys. The clinical case-bases contain 'snapshots' of actual past clinical cases encountered by healthcare practitioners and experts. Healthcare scenario-bases contain 'hypothetical' (but mimicking real) problem situations encountered by healthcare experts together with their intuitive problem solving methodology or tacit healthcare knowledge [4]. Document-bases serve to provide textbook-type knowledge and reference to the user.

5. Concluding remarks

In our work, we have identified the efficacy of intelligent agents in the IHKA info-structure to address pressing issues concerning healthcare knowledge retrieval and procurement. We argue that the IHKA adds value to the more 'traditional' healthcare information/knowledge systems because the agents are designed to capitalize on not just references to empirical data, past clinical cases and static textbook-type documents in their retrieval efforts, but also on experiential and intuitive tacit healthcare knowledge. The use of agent technology is of relevance here in view that, in real life, we expect assistants to be sufficiently competent and independent in delivering the required results. Therefore, we believe that the utilization of agent technology in healthcare knowledge management, especially for knowledge retrieval and procurement, will prove to be a highly viable solution in providing the necessary assistance to healthcare practitioners whilst procuring relevant healthcare knowledge.

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