TICSA Approach: Five Important Aspects of Multi-agent Systems

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Abstract. The issues of distributed and heterogeneous information, lack an underlying knowledge base, autonomy of the information resources, dynamic nature of the information retrieval process and dramatically increase of the available information are major factors hindering efficient and effective use of the available information. In this paper we explain the importance of multi-agent systems in addressing these issues effectively and illustrate this on an example of multi-agent system designed to intelligently retrieve human disease information. We also present a conceptual framework (TICSA) which focuses on the five different aspects of multi-agent systems namely, agent Types, Intelligence, Collaboration, Security and Assembly. This framework can be used to provide insight and guidance during the multi-agents systems design.

Keywords: multi-agent system, multi-agent system design, human diseases, information retrieval, biomedical information systems.

1 Introduction

Agents are intelligent programmes used for perform various actions. They can answer queries, retrieve information, make decisions and communicate with computer systems, other agents or users. Agents are capable to perform their actions autonomously and are sociable, reactive and proactive in an information environment [1]. The main features of agents are their autonomous, intelligent, mobile, cooperative and collaborative capabilities. The main operations of a multi-agent system are based on effort of collaborative working agents; different types of agents are working cooperatively towards a shared goal. The multi-agents systems greatly contribute to the design and implementation of complex biomedical information systems.

Effective implementation of multi-agent systems within biomedical domain could result in a revolutionary change that will positively transform the existing biomedical system. The main issues hindering effective use of the available information include [2]:

1. size of the available information
2. autonomous, distributed and heterogeneous nature of the information resources, and
3. lack of tools to analyse the available information and derive useful knowledge from it.

The users are faced with additional difficulties which include [2,3]:

a) rapid increase of medical information (new papers or journals are being published with a high rate)

b) inconsistent structures of the available information (as a result of autonomy of information resources)

c) related, overlapping and semi-complementary information

d) existence of complex diseases e.g. mental illnesses or diabetes. The complex diseases are caused by a number of genes usually interacting with various environmental factors [4].

In this paper we propose multi-agent systems as a solution to those problems. Related work is discussed in Section 2. In Section 3, we discuss the design of multi-agent systems used to intelligently retrieve information about human diseases. Each subsections of the Section 3 correspond with a specific aspect of the TICSA generic conceptual framework that can be used to guide the system design. We give our final remarks in Section 4.

2 State of play

Multi-agent systems are being used more and more in the medical domain. Some of these agent-based systems are designed to use information within specific medical and health organizations, others use information from Internet.

The information available to organization-based systems is limited to a specific institution and these multi-agent systems help the management of the already available information. They do not have a purpose of gaining new knowledge regarding the disease in question. For example, Agent Cities [5] is a multi-agent system composed of agents that provide medical services. The multi-agent system contains agents that allow the user to search for medical centres satisfying a given set of requirements, to access his/her medical record or to make a booking to be visited by a particular kind of doctor. AADCare [6] agent architecture is a decision support system for physicians. It connects patient's records with the predefined domain knowledge such as knowledge regarding a specific disease, a knowledge base of clinical management plans, a database of patient records etc. MAMIS [7] is a Multi-Agent Medical Information System facilities patient information search and provides ubiquitous information access to physicians and health professionals.

Other multi-agent systems retrieve information from the Internet. BioAgent [8] is a mobile agent system where an agent is associated to the given task and it travels among multiple locations and at each location performs its mission. At the end of the trip, an information integration procedure takes place before the answer is deployed to the user. Holonic Medical Diagnostic System [9] architecture is a medical diagnostic system that combines the advantages of the holonic paradigm, multi-agent system technology and swarm intelligence in order to realize Internet-based diagnostic system for diseases. All necessary/available medical information about a patient is kept in exactly one comprehensive computer readable patient record called computer readable patient pattern (CRPP) and is processed by the agents of the holarchy. Different web crawling agents [10] have been designed to fetch information about diseases when given information about genes that when mutated may cause these diseases.

The importance of use of the multi-agent system within a specific institution such as hospital or a medical centre is great. In this project we focus on a different level of contribution, namely, on making a channel through which newly available and valid information from the research arena will flow into the medical practice to be effectively implemented there. Lots of the information is available but due to the large body of information some important information may escape the users notice and be neglected.

The BioAgent system could be used by our system with some modifications. We can use the same principle of agent migration among multiple locations, information retrieval from each location and information integration at the end of the trip. Only the information we are interested in is not regarding the genome analysis and annotation but human diseases. There is need to design a multi-agent system for the purpose of dynamic information retrieval regarding common knowledge of human diseases as such a system does not exist yet. Holonic Medical Diagnostic System is Internet-based system but it operates on the basis of the information specified in the patient record and collecting the evidence for diagnosis of this patient. Web crawling agents focus only on genetic causes of human diseases. In this project, we propose a system that integrates information regarding disease types, symptoms, causes and treatments of a disease in question. This multi-faceted approach is very significant in the domain of complex diseases where a specific combination of genetic and environmental factors causes a specific type of a specific disease.

3 TICSA approach

In this section, we describe how we use the Agent Design Methodology described in [11] to design a multi-agent system for retrieval of information about human diseases. The Agent Methodology consists of the following five steps:

1. Identify Agent **T**ypes According to Their Responsibilities
2. Define Agent's **I**ntelligence
3. Define Agent's **C**ollaborations
4. Protect the System by Implementing **S**ecurity Requirements
5. **A**ssemble Individual Agents

The key aspect of each step is represented in Figure 1.

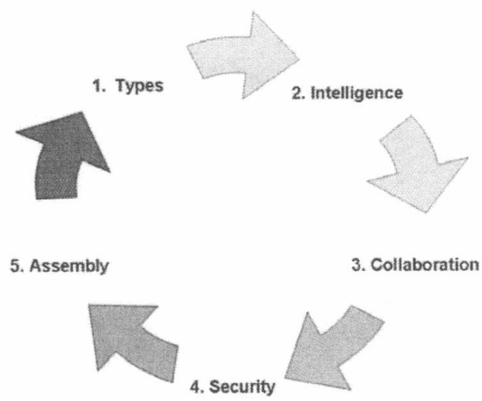

Figure 1 Diagram representing main focus of each Agent Design Methodology step

3.1 Identify Agent Types According to Their Responsibilities

A multi-agent system is a community of agents. The agents are characterized by different but complementary capabilities and are cooperatively working towards the shared goal. The agents are required to work in unity, coordinate their actions and integrate their results.

When identifying agent types, it is important to:

- establish intuitive flow of problem solving, task and result sharing
- identify agent functions needed to establish this kind of flow
- identify agent roles according to these functions

In our example, a user queries the multi-agent system and the multi-agent system answers the query in an intelligent way. A range of actions is required to provide the user with correct answer. These include (1) translation of user's query into a machine-understandable language, (2) sharing of the information retrieval task between different agents, (3) activation of appropriate agents to retrieve the target information, (4) analysis of the retrieved information, (5) selection of appropriate information, (6) assembly of the selected information, and (7) presentation of the assembled information to the user.

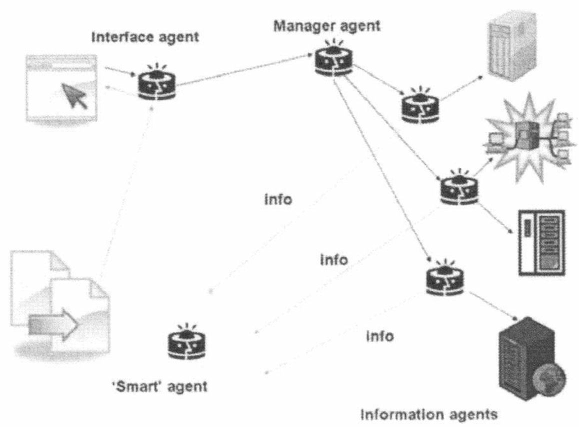

Figure 2 Interface, 'Manager', Information and 'Smart' agents

We have identified four agent types required to fulfil the overall task of intelligent information retrieval. The organization of the different agent types within the information system is presented in Figure 2. All agents within this information system are dependent on each other for the realization of the shared goal. Their common goal is to answer the user's query in the most efficient way. To be able to achieve this, they have different functions and work on different levels within the multi-agent system. In this distributed multi-agent system architecture, *Interface agents* assist users in formulating queries as well as in presenting assembled information back to the user. Interface agents communicate user's request to Manager agents. *Manager agents* then assign specific tasks to Information agents. *Information agents* retrieve requested information from a wide range of biomedical databases. Each Information agent may have a set of assigned databases that it needs to visit in order to retrieve requested information. Information agents hand over retrieved information to Smart agents. *Smart agents* analyze this information, select relevant information, assemble it correctly and pass this information to Interface agents to be presented to the user as an answer to his/her query.

3.2 Define Agent's Intelligence

The agents need to be equipped with the knowledge that will enable them to perform their task intelligently e.g. to decompose overall problem, to retrieve relevant information, to communicate with each other, to analyze and manipulate information, present information in a meaningful way, etc. Currently, knowledge bases have been predominantly used to provide agents with intelligence and enable them to perform their action efficiently and effectively. Ontologies are high expressive knowledge models and use of ontologies over knowledge bases is preferred [12].

In our previous works [13], we have explained design of Generic Human Disease Ontology (GHDO) as being composed of four sub-ontologies: Disease Types, Symptoms (Phenotype), Causes and Treatments (see Figure 3). This ontology can be used to equip agents with intelligence and enable them to retrieve relevant information intelligently.

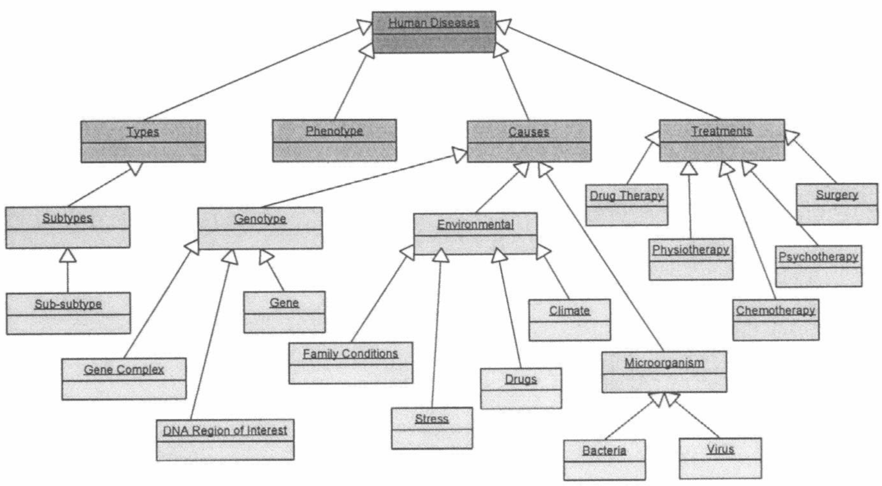

Figure 3 Four subontologies of the Generic Human Disease Ontology

In the sequel of this section, we will explain how the GHDO can be used increase intelligence as well as control over the information retrieval process. Interface agent maps the user's query to GHDO concepts, and assembles the mapped GDHO concepts into a Specific Human Disease Ontology template (SHDO template). This SHDO template is subset of the GHDO, and is a template into which the retrieved information will be filled in. To enable effective problem decomposition and task sharing among different agents, Manager agent decompose the SHDO template according to the four sub-ontologies and assigns relevant tasks to appropriate Information Agents. Information agents retrieve the target information and pass it over to Smart agent. Smart agent analyzes this information, selects relevant information and assembles it into the SHDO template. This step results in a Specific Human Disease Ontology (SHDO) that is presented to the user as the answer to his/her query. With the focus on the ontology, this process is shown in Figure 4.

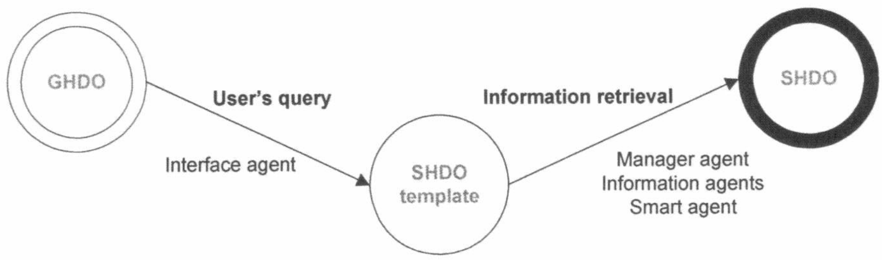

Figure 4 GHDO, SHDO template and SHDO

3.3 Define Agent's Collaborations

In the first stage of the TICSA approach, we described how to identify different agent types according to their different functions and roles within the multi-agent system. In this stage, we focus on structural organization and position of agents within the system. The aim of this step is to:

- define system architecture that will enable the most optimal performance of agents
- establish correspondence between different agent types and positions of these agents within the multi-agent system

Here it is important to organize the agents so that the problem solving process can easily flow towards its completion and that the communication between different agents can be easily established. In combination with capabilities of individual agents, these two features are major factors determining efficient and effective system performance. Sometimes, a system structured in a simple way functions the best. In other cases, a complex system may be a better choice for the task at hand.

We have proposed a GHDO-based Holonic Multi-agent Structure (GHMS) [14] (shown in Figure 5) as a nested hierarchy of four holarchies in which each of the four GHDO dimensions (Disease types, Symptoms, Causes and Treatments) is associated with one holarchy. The information is interpreted and analyzed at the higher levels of the hierarchy while collection of the data happens at the lower level of the holarchy.

Highest in the agent hierarchy is Disease Mediator Agent. For each of the four holarchies, we have corresponding Mediator Agent, Specialist and Representative Agents.

Disease Mediator Agent (DMA) is the main entry point of GHMS. It also functions as Interface agent and creates SHDO template according to user's query. On the basis of the SHDO template, DMA decides which of the four holarchies needs to be activated. For example, sometimes a user may be interested only in the treatments of a disease so that there is no need to deploy the Disease types, Symptoms and Causes holarchy. DMA also corresponds to the first level Manager agent.

Mediator Agents (MAs). Each branch of the main entry point of GHMS (DMA) has its own mediator agents, respectively Disease Types, Symptoms, Causes and Treatments Mediator Agents (D-MA, S-MA, C-MA and T-MA). Their task is to decide which other Specialist Agents (SAs) need to be activated to retrieve requested information. MAs correspond to the second level Manager agents.

Specialists Agents (SAs). Holarchy inner nodes represent Specialist Agents (SAs). We differentiate Disease types, Symptoms, Causes and Treatments Specialists Agents (D-SA, S-SA, C-SA and T-SA). They are specialists on a specific topic of corresponding subontology. For example, within Causes sub-ontology one C-SA may be specialized in the genetic causes of a disease while another C-SA may be a specialist on the environmental causes of a disease.

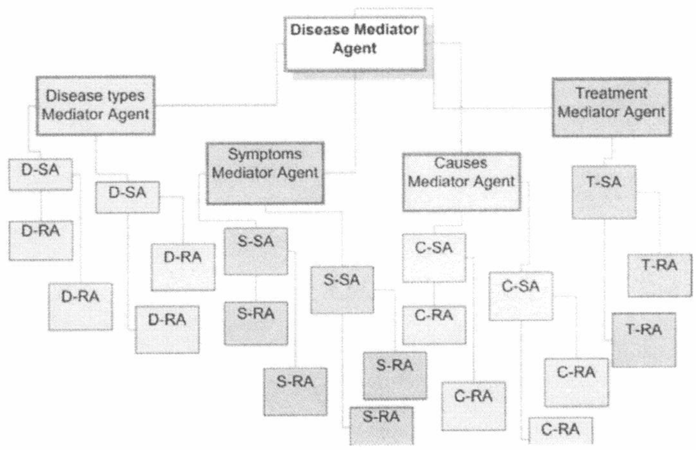

Figure 5 GHMS structure

SAs assign different tasks to different RAs. SAs correspond to the third level Manager agents. After RAs have returned their data, SAs interpret, analyse, select and assemble these data into relevant part of the SHDO template. SAs correspond to the third level Smart agents.

SAs pass the assembled information onto MAs which also receive assembled information from other SAs of the same sub-ontology. The MAs correspond to the second level Smart agents and they analyze all this information, select relevant information and merge it into the SHDO template. At the end of this process, the SHDO template contains information relevant to specific sub-ontology. This information is forwarded to DMA.

DMA receives the four SHDO sub-ontologies which contain information regarding disease types, symptoms, causes and treatments, merges this complementary information into SHDO and present this information to the user. MAs correspond to the first level Smart agent.

Representative Agents (RAs). The leaves are so-called Representative Agents (RAs). We differentiate Disease types, Symptoms, Causes and Treatments Diseases Representative Agents (D-RA, S-RA, C-RA and T-RA). Each RA is an expert on the lowest level concept within the ontology. Note that RAs differ from SAs in that they need to recognize the significant information inside the appropriate database and retrieve that information. RAs correspond to the Information agents.

3.4 Protect the System by Implementing Security Requirements

Security plays an important role in the development of multi-agent systems. The risks of jeopardizing the system security must be minimized by providing as much security as possible. The aim of this stage is to:

- identify critical security issues within the multi-agent system
- effectively address the identified issues
- implement the security requirements within the system

In the GHMS environment, all five security properties [15] of authentication (proving the identity of an agent), availability (guaranteeing the accessibility and usability of information and resources to authorized agents), confidentiality (information is accessible only to authorized agents), non repudiation (confirming the involvement of an agent in certain action) and integrity (information remains unmodified from source entity to destination entity) should be taken into consideration. Additional agent's characteristics such as compliance (acting in accordance with the given set of regulations and standards), service (serving one another for mutually beneficial purposes) and dedication (complete commitment of the agents to the overall goal and purpose of the multi-agent system), greatly contribute to the security of the overall system.

The abovementioned properties are critical inside the multi-agent system as well as outside the multi-agent system, such as during the agent interaction with the environment. After the identification of required security properties, it is necessary to effectively address and implement them within the multi-agent system. As different agents have different functions within the system, some agents will be more critical than others in regard to the security of the system. As a consequence, the critical agents will be assigned more security requirements than the others.

3.5 Assemble Individual Agents

In the previous sections, we have discussed functions of agents within a system as well as equipping the agents with intelligence and enabling them to perform these functions optimally, collaborative aspect of agents and security requirements. In this step we focus on bringing these different aspects together and creating a variety of agents. For each agent, it is important to:

- identify required agent components
- assemble the components into an unified system i.e. individual agents

These agent components may include the Human interface (interaction with users), Agent interface (interaction with agents), Communication component (processing messages), Cooperative (negotiation, cooperation and coordination), Procedural (problem solving procedures, goal prioritization), Task (agent-specific), Domain (domain of interest) and Environment knowledge (in which the agent is situated), History files (past experiences), and so on.

We have chosen the assembly to be the last design step as many different agents will have a number of components in common. The variety of agents within a multi-agent system can be achieved in three different ways: (1) different components that are used to construct different agents are the same, but the *content* of these components is different for different agents, (2) the content of the components used to construct different agents are the same, but different agents are constructed by a different *combination* of used components and (3) the third and most common option is that different agents differ in the *combination* of the components used to construct them, *and* in the *content* of these components.

4 Conclusion

In this paper, we discussed current issues associated with the access, storage, management and retrieval of biomedical information and proposed multi-agent system as possible solution to these problems. We discussed design of the multi-agent systems using the TICSA (Types, Intelligence, Collaboration, Security and Assembly) approach and illustrated the idea on the design of ontology-based multi-agent system for retrieval of information about human diseases.

The implementation of multi-agent systems within health and medical domain on a larger scale will result in positive transformation of world-wide health and medical research and management to a more effective and efficient regime.

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