Cognitive Medical Multiagent Systems

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Abstract

The development of efficient and flexible agent-based medical diagnosis systems represents a recent research direction. Medical multiagent systems may improve the efficiency of traditionally developed medical computational systems, like the medical expert systems. In our previous researches, a novel cooperative medical diagnosis multiagent system called CMDS (Contract Net Based Medical Diagnosis System) was proposed. CMDS system can solve flexibly a large variety of medical diagnosis problems. This paper analyses the increased intelligence of the CMDS system, which motivates its use for different medical problem's solving.

Keywords: medical expert system, intelligent system, medical multiagent system, complex system, knowledge-based medical agent, medical diagnosis system, medical decision support

1. Introduction

Results described in the literature, prove that the intelligence of a computational system can offer advantages in problem solving versus a system that does not have intelligence [3, 5, 10, 49]. Sometimes a system's intelligence can be measured according to how efficiently and flexibly the system can solve problems (intelligence in problem solving). The purpose of the endowment of an agent with intelligence consists in obtaining improvements in problem solving. For example, solving problems whose description contains some uncertainties or whose solving is partially known.

In our previous researches, a novel medical diagnosis system called *CMDS* (*Contract Net Based Medical Diagnosis System*) was developed [13]. This paper analyses the *CMDS* system's intelligence, which motivate its use for difficult problems solving that appear in the medical domain (medical diagnosis and medical decision support).

The upcoming part of the paper is organized as follows: Section 2 presents some aspects related with computational systems used in the medical domain; in Section 3 there are presented some aspects related with intelligent systems; in Section 4 agent-based medical diagnosis systems are presented; Section 5 presents the *CMDS* system; Section 6 analyses the intelligence of the *CMDS* system; in Section 7 there are presented the conclusions of the research.

2. Medical computational systems

In medical domains, there are proposed and used many medical systems that operate in isolation or cooperate with each other [3, 22, 8, 14, 15, 16, 17, 37, 38]. The paper [39] motivate that appropriate use of available information, knowledge and communication technologies can make a significant contribution towards achieving a sustainable health system and that the adoption of semantically interoperable health information systems.

As more health-care providers invest in computerized medical records, more clinical data is made accessible. Extracting medical information from huge repositories of data are becoming increasingly important for purposes such as offering better care [50].

The paper [15] describes intelligent medical diagnosis systems with built-in functions for knowledge discovery and data mining. The intelligence is considered based on the capacity of the system to learn. Diagnosing rules generated by learning can be used in diagnosis processes.

In the paper [42] is proposed *CoOL* a formal context model based on ontology to address issues including semantic context representation, context reasoning and knowledge sharing, context classification, context dependency and quality of context. The main benefit of this model is the ability to reason about various contexts.

BioDASH [40] is a Semantic Web prototype of a Drug Development Dashboard that associates disease, compounds, drug progression stages, molecular biology, and pathway knowledge for a team of users. Data from several sources are integrated, on the client, and explored in a variety of views. The focus of the work is on combining the multiple resources semantically.

BHIPS (*Behavioral Health Integrated Provider System*) [41] is Web-based, open-source software that allows behavioral health providers to integrate tracking, clinical, and billing data into a comprehensive behavioral health service delivery system. The system can be rolled out and adapted in response to changing needs. One of the most interesting aspects of BHIPS development is the manner in which continuous, open, and frank dialogue between the end users and the system developers is used to inform system evolution.

Artemis [2] represents a development of semantic web services based interoperability framework for the healthcare domain. In *Artemis* infrastructure healthcare institutes keep their proprietary systems and expose their medical applications as web services. *Artemis* addresses the interoperability problem in healthcare domain in two respects: semantic interoperability and functional interoperability. Semantic interoperability is the ability for information shared by systems to be understood at the level of formally defined domain concepts so that the information could be processed by the receiving system. Functional interoperability is the ability of two or more systems to exchange information.

ASEMR [20] combines three ontology's with rules in order to enhance the accuracy of EMRs both by providing clinical decision support and by improving the correctness of medical coding therefore reducing the number of rejected claims. The presented semantic approach, which improves patient care and enables healthcare providers to complete all charge entry and documentation.

SAMHSA (*Substance Abuse and Mental Health Services Agency*) [1] facilitates the integration of state-level data across state mental health, state substance abuse, and state Medicaid agencies. The system requires collecting encounter-level data; using coding that is compliant with the Health Insurance Portability and Accountability Act, including national provider identifiers; forging linkages with other state data systems and developing unique client identifiers among systems; investing in flexible and adaptable data systems and business processes; and finding innovative solutions to the difficult confidentiality restrictions on use of behavioral health data.

3. Cognitive agent-based systems

The development of cognitive systems represents an important research direction [1, 44, 3, 4, 5, 6, 22, 8, 9, 36, 24]. Agent-based technologies represent one of the best-fitted alternatives for the creation of intelligent systems. Basic proprieties necessary to an intelligent agent consists in the increased autonomy in operation and the capacity of communication and cooperation [43, 5]. These proprieties are necessary in the endowment of the agents with capacities specific to the intelligent systems. In the literature, there are described intelligent agents [1, 3, 4, 5, 7, 8]. Agents capable of learning autonomously are often considered intelligent [3, 5]. Autonomous learning allows the agents to adapt for efficient solving of the problems. Another propriety that is sometimes associated with intelligence consists in the capacity to help other agents and humans during problem solving, sometimes in decision support.

The intelligence of the agents should often be considered based on the types of the agents, for example [44]: robotic agents' intelligence, static software agents' intelligence and mobile software agents' intelligence. There are many static software agents that could be considered intelligent [3, 5]. Software mobile agents are more limited in intelligence than the software static agents [6, 11, 12]. The limitations of the mobile agents in intelligence have practical motivations [11]. The endowment of a mobile agent with intelligence increases its body size and its behavioral complexity. The transmission of a large number of intelligent mobile agents in a network may overload the network with data transmissions. A large number of intelligent mobile agents at a host may overload the host with data processing.

In a cooperative multiagent system, the intelligence could be considered at the level of the system where the agents operate [43, 5]. If the agents cooperate efficiently, they can solve intelligently difficult problems. The intelligence of an efficiently cooperating multiagent system could be higher than the intelligence of the member agents. In the literature [43, 10], there are described multiagent systems, some of them made up of relatively simple agents that could be considered intelligent at the level of the multiagent system in which they operate.

4. Agent-based medical systems

Medical expert systems represent relatively classical applications used for medical diagnoses elaborations [18, 19, 45, 21, 7, 23, 24, 25, 27, 26]. As examples of developed medical expert systems, we mention: *MYCIN* [19], *Casnet* [26], *Dimitra* [25], *Cardiag2* [45], *PUFF* [23], *Gideon* [21], *HDP* [7] and *CASEY* [27].

Recently, there have been developed agent-based medical diagnosis systems that eliminate some disadvantages of the medical expert systems [3]. Motivations of the use of agents for different medical problems solving consist in the proprieties of the agents, like: increased autonomy in operation, capacity of communication, autonomous learning capacity and capacity to interact with the environment. Intelligent agents used in medicine may increase the accuracy of diagnostics elaborated by physicians (an agent may help a human medical specialist in medical decisions elaborations, also he may verify medical hypothesis elaborated by the human medical specialists) and may improve the solving of medical tasks that must be fulfilled in healthcare processes.

As examples of applications of the agents for fulfilling medical tasks, we mention: *patients management and monitoring* [28, 29, 30]; *healthcare, ubiquitous healthcare and web-enabled healthcare* [31, 32, 35], *telehealth* [33], *spreads simulation of infectious disease* [34] etc.

The paper [14] analyzes different aspects of the multiagent systems specialized in medical diagnosis. Understanding of such systems needs a high-level visual view of how the systems operate as a whole to achieve some application related purposes.

OnkoNet mobile agents have been successfully used for patient-centric medical problems solving [32]. It is introduced the notion of ubiquitous healthcare, addressing the access of health services by individual consumers using mobile agents. This access requires medical knowledge about the individual health status. The presented work emerged from a project covering all relevant issues, from empirical process studies in cancer diagnosis/therapy, down to system implementation and validation.

Clinical decision support systems [47, 48] form a significant part of the field of clinical knowledge management technologies, being interactive computer programs, which are designed to assist physicians and other health professionals with decision-making tasks. Agent oriented techniques are important new means in analyzing, designing and building complex software systems. In the paper [46] an intelligent multiagent system, named IMASC, for assisting physicians in their decision-making tasks. The system was proposed for assisting physicians in diagnosing the heart disease.

In [10], it is proposed a medical diagnosis multiagent system that is organized according to the principles of swarm intelligence. It consists of a large number of agents that interact with each other by simple indirect communication. The proposed multiagent system's real power stems from the fact that a large number of simple agents collaborate in a reliable way with the purpose of elaborating diagnostics. The intelligence of the proposed system can be considered based on the agents' capacity to learn.

5. The CMDS Cognitive Medical System

In our previous researches a novel cooperative medical diagnosis system called *Contract Net Based Medical Diagnosis System* was proposed [13]. *CMDS* (*Contract Net Based Medical Diagnosis System*) system is made up of set $Mda \cup Asg$ of members, artificial agents and physicians specialized in different medical domains. In the following, all the members (artificial and human) of the diagnosis system are called agents. A *CMDS* system can solve diagnosis problems randomly transmitted for solving. A problem is initially transmitted to a medical agent member of the system, and, subsequently, the system will handle autonomously the problem solving.

Figure 1 presents the *CMDS* system's architecture. $Pr=\{Pr_1, Pr_2,\ldots, Pr_q\}$ represent problems that must be solved by the system. $Mda=\{Mda_1, Mda_2,\ldots, Mda_n\}$ represent agents specialized in medical diagnosis, physicians and medical expert system agents. $Asg=\{Asg_1, Asg_2,\ldots, Asg_k\}$ represent assistant knowledge-based agents. The assistant agents are capable of helping the medical agents during the problem's solving processes.

The algorithm *Problem Solving* describes briefly how a medical agent denoted Mda_i ($Mda_i \in Mda$) operates when it receives an initially transmitted medical diagnosis problem or a problem solving statement. The algorithm has been described with details in the paper [13]. The paper [13] presents the medical knowledge detained by the artificial medical agents. An agent is capable [13] of solving a problem, if it has the necessary specialization (problem solving knowledge) and resources for the solving of the problem in the maximum admitted time.

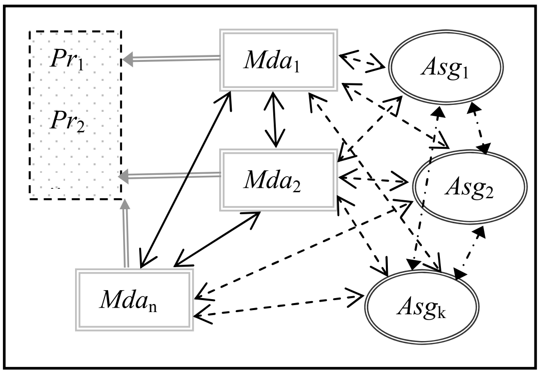

Figure 1. CMDS medical diagnosis system

The agents from the set *Mda* have specializations sets in medical diagnosis. The agents from the set *Asg* have specializations sets that allow the assistance of the agents from the set *Mda*. An agent is called capable of processing a problem, if it has the necessary specialization and resources to process the problem. A problem processing has as objective to obtain a more complete description of the solution. During a problem solving the solution description is completed step by step.

Algorithm Problem Solving
Step 1 - The problem solving.
$St_d \rightarrow Mda_i$.
If (Mda_i is capable to processes St_d) *then*
$Mda_i(St_d)$ » St_h.
If (St_h contains the St_d solution) *then*
Goto Step 2.
Else
Mda_i (St_h) » *an*.
Mda_i (*an*) $\rightarrow$ *Acg*.
EndIf
else
Mda_i (St_d) » *an*.
Mda_i (*an*) $\rightarrow$ *Acg*.
EndIf
While (the waiting time to *an* is not expired) *do*
@Mda_i evaluates the bids to *an*.
EndWhile
@Mda_i awards the problem solving statement to a suitable agent Mda_b ($Mda_b \in Acg$).

@Mda_i receives the St_q problem statement from Mda_b.
Step 2 - The problem solution formation.
@The solution sol_d is extracted from the latest problem solving statement.
@The least problem solving statement and sol_d is transmitted to the St_d sender.
EndProblemSolving.

In the algorithm presented above, there are used the following notations: "→" denotes a communication process; "»" denotes a problem processing; St_d denote the problem solving statement; Mda_i and Mda_b denotes medical agents; sol_d denotes the solution of St_d; St_h denotes a problem solving statement; *an* denotes an announcement; *Acg* ($Acg \subset Mda$) denotes a set of medical agents to whom the announcement *an* can be transmitted. The solving of a problem is sometimes a recursive process to which more agents can contribute. A problem statement is sent from agent to agent until the problem is solved. The algorithm *Problem Solving* describes a cooperative problem solving by medical agents. During its operation a medical agent may require the help of assistant agents. The paper [13] describes how an assistant agent helps a medical agent. Each human and artificial medical agent knows at least one assistant agent whose help may be required. If it is necessary, an assistant agent may cooperate with other assistant agents to fulfill the requirement.

Formula (1) illustrates a problem solving process.

$$St_a(Sp_q) \;»\; St_b(Sp_w) \;»\; \ldots \;»\; St_y(Sp_r) \;»\; St_g. \qquad (1)$$

Sp_q, Sp_w,…, Sp_r represent the specializations used during the St_a solving. Processing St_a by using Sp_q is obtained St_b (a new problem solving statement). Processing St_b using Sp_w is obtained St_c. Processing St_y using Sp_r is obtained St_g. St_g is the problem solving statement obtained after all the realized processing (St_g contains the solution of St_a).

A problem solving statement (2) describes medical knowledge $Kng=\{Kng_1, Kng_2,\ldots, Kng_n\}$ obtained during a diagnosis problem solving.

$$< id_1\,|Kng_1;\; id_2\,|Kng_2;\ldots;\; id_n \,|\, Kng_n\; >. \qquad (2)$$

As examples of information that can be contained in a parameter Kng_c ($Kng_c \in Kng$) from (2), we mention: an illness symptoms, illnesses from the past, a diagnostic etc. Initially a problem solving statement contain information that describes the illness (for example, the history of the patient's illness symptoms specified by the patient). During the solving of the problem, the problem solving statement is changing. The final problem solving statement will contains the established diagnostic. During a problem solving, some parameters' values may not be completed (for example, it is not necessary to retain the history of the diagnosed illness symptoms). Each parameter in (2) has associated a unique natural number as identifier. The identifier of a parameter indicates the type of information that can be retained in that parameter. For example, *type*(id_c) = *syndromes* specifies that the parameter Kng_c (associated with the identifier id_c) may contain as values the specifications of the syndromes of an illness.

An announcement denoted *an* has the parameters (3).

$$an = < St_j;\; Deadline_j;\; Eligibility_j;\; Emit_j >. \qquad (3)$$

St_j represents the announced problem. $Emit_j$ numerical value specifies the initial moment of time when *an* is formed. $Deadline_j$ numerical value specifies the maximum admitted time for the St_j processing. Based on $Deadline_j$ and $Emit_j$ values, an agent who receives *an* specify the remaining time for St_j processing. $Eligibility_j$ value specifies the eligibility criteria of the bid acceptance.

A response $Resp_j$ of an agent Mda_i to the St_j problem solving statement announcement *an* has the parameters (4).

$$Resp_j = < Tm_i;\; Of_i;\; an;\; Cb_i;\; Sc_i >. \qquad (4)$$

Cb_i values specify the specializations that Mda_i can use in the St_j processing. Tm_i numerical value specifies the estimated processing time by Mda_i. Of_i value specifies the bid to St_j processing, Of_i = '*yes*' (specifies acceptance) or Of_i = '*no*' (specifies rejection). When a medical agent receives the bids to an announcement, using the information contained in the responses, he can improve the following decisions about what to do with the announced problem. Sc_i values specify the estimated specializations by Mda_i, necessary in the St_j processing. *an* value specifies the announcement identifier.

6. Intelligence of the CMDS System

The main proprieties for the artificial agents' members of the *CMDS* system consist in the increased autonomy in operation, communication and cooperation capability. The artificial agents' members of the *CMDS* system can be endowed with autonomous learning capacity. They can learn new knowledge and can improve the detained knowledge accuracy. The agents can learn during the problems' transmission for processing. When an agent receives a response to an announcement, he may learn information that can improve the accuracy of the medical decisions that must make and may improve the efficiency of its following operation. A response to an announcement can contain auxiliary information that may help the agent in the decision elaboration.

From the responses to an announcement, an agent can learn information like:

- what agents can usually overtake problems for processing (this information may limit its future interactions);
- the medical knowledge detained by different agents;
- what agents usually answer fast to the announcements.

A medical agent may require the help of an assistant agent during its operation. For example, in a situation when the medical agent does not have a specialization, however, he must require the help of an assistant agent, who has the necessary specialization. If an assistant agent cannot solve an overtaken problem, then he can cooperate with other assistant agents in order to solve the problem. For a physician it is necessary to know a single medical agent, who if it is necessary can cooperate with other assistant agents to fulfill the physician's requirement.

In the case of a solved problem, the final problem solving statement contains all the necessary information in a learning process, which consists in the completely obtained problem description and the established diagnostic. The agents (artificial agents and humans) can learn from a final problem solving statement. The information contained in a problem solving statement are understandable to the physicians and artificial agents. Each information contained in a problem solving statement has associated the type of the medical information: treatment, illness symptoms, illness syndromes, etc. The agents can learn new medical diagnosis problems solving or can improve the detained medical diagnosing knowledge accuracy. For example, an artificial medical agent may learn new symptoms of an illness.

Assistant agents can find the solutions to hypotheses elaborated by physicians. As an example, we mention the situation when a physician wants to find the answer to a medical issue by consulting more physicians. In order to find the answer, the physician can transmit the issue to an assistant agent, who will search for the physicians capable to answer to the issue. The assistant agent transmits the issue to the physicians, collecting and transmitting their answer to the physician sender of the announcement. The physician sender of the medical issue will establish the answer based on the received answers to the issue. As an example of a medical issue that can be solved, we mention "what is the best-fitted medicine to cure an illness".

In the *CMDS* system, the intelligence could be considered at the level of multiagent system. The intelligence of a cooperative multiagent system is increased due to the agents' efficient cooperation. The intelligence of the *CMDS* multiagent system is higher than the intelligence of the system's members. An important advantage of the *CMDS* system consists in the flexibility of operation. A diagnosis problem is transmitted to an agent member of the system, after which the system will handle autonomously the problem solving, by transmitting the problem from agent to agent until the problem is solved. The specializations necessary for a diagnosis problem solving are not specified in advance, the members of the system must discover cooperatively the problem solving. The specializations necessary to a problem solving may be distributed between more agents. Artificial medical agents and physicians may have only a limited quantity of medical knowledge.

7. Conclusions

Agents are used for difficult problems solving in many domains. The motivations for the use of agents in the medical domain consist in the multitude of aspects that the agents can analyze during the diagnostics elaborations and the realization of different tasks in healthcare. Agent-based approaches may integrate and extend different problem solving technologies (for example, we mention medical agents that extend the medical expert systems).

In previous researches, we have proposed a novel cooperative medical diagnosis system called *Contract Net Based Medical Diagnosis System*. The *CMDS* (*Contract Net Based Medical Diagnosis System*) system has some characteristics of the intelligent systems. The main advantage of the *CMDS* system consists in its autonomy and flexibility in handling medical diagnosis problems. During the diagnosis processes, there are transmitted information that allows the physicians and artificial agents to improve the detained knowledge accuracy.

The main motivation that sustains the intelligence of the *CMDS* system consists in the combination of the humans thinking and the artificial agents processing advantages during the medical problems solving. The physicians can solve difficult problems using their intelligence specific to the humans (intelligence that cannot be attained by the actual computational systems). The artificial agents can solve problems verifying many conditions that could be ignored by humans, which may have as result the elimination of some mistakes from the physicians' decisions. For example, a physician may forget to take into consideration information from a patient's medical history when he/she diagnoses the patient's illness (for example a known allergy of a patient specified in its medical history).

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