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A NOVEL MEDICAL DIAGNOSIS SYSTEM

Barna Iantovics

Abstract. In this paper, we propose a novel cooperative heterogeneous medical diagnosis system composed from humans and artificial agents specialized in medical diagnosis and assistant agents. The cooperative problem solving by the proposed diagnosis system combine the human and artificial systems advantages in the medical diagnosis problems solving.

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1. Introduction

The purpose of the study consists in the development of an open, large-scale medical diagnosis system capable of solving a large variety of medical diagnosis problems. In this paper, we propose a novel medical diagnosis system. The medical diagnosis system is a heterogeneous system with human and artificial members specialized in medical diagnosis. The cooperative solving of the medical diagnosis problems by the proposed system is partially based on the cooperative problem solving using the contract net protocol [1, 2, 3, 4, 5] and the general cooperative problem solving described in the paper [6]. The main advantage of the proposed medical diagnosis problem solving is the flexible and precise solving of a large variety of medical diagnosis problems, which's solving require knowledge from different medical diagnosis domains. The necessary knowledge to the diagnosis problems solving are not specified in advance, the diagnosis system members must discover cooperatively the problems solving.

2. Medical diagnosis systems

In the medical domains are proposed and used many medical diagnosis systems that operates in isolation or cooperates [7, 8, 9, 10, 11, 12, 13, 14, 15]. The paper [7] describes the state of the art medical information systems and technologies at the beginning of the 21st century. There is also analyzed the complexity of construction of full-scaled clinical diagnoses as the basis of medical databases. The paper [8] analyzes different uncertainty in the medical diagnosis. In the following we enumerate some systems specialized in medical diagnosis.

The paper [9] analyzes different aspects of the multiagent systems specialized in medical diagnosis. Understanding such systems needs a high-level visual view of how the system operates as a whole to achieve some application related purpose. The paper analyzes a method of visualizing, understanding, and defining the behavior of a medical multiagent system.

The paper [10] presents a holonic medical diagnosis system that combines the advantages of holonic systems and multiagent systems. The presented multiagent system is an Internet-based diagnosis system for diseases. The proposed holonic medical diagnosis system consists of a tree-like structured alliance of agents specialized in medical diagnosis that collaborate in order to provide a viable medical diagnosis.

The paper [11] propose a methodology, based on computer algebra and implemented in CoCoA language, for constructing rule based expert systems, that can be applied to the diagnosis of some illnesses.

The paper [12] describes intelligent medical diagnosis systems with built-in functions for knowledge discovery and data mining. The implementation of machine learning technology in the medical diagnosis systems seems to be well suited for medical diagnostics in specialized medical domains.

Various diagnostic technologies are studied and used. It is necessary to develop automatic diagnosing processing system in many medical domains. The paper [13] presents a cardiac disease analyzing method using neural networks and fuzzy inferences.

The paper [14] presents a cooperating expert system FELINE composed of five autonomous intelligent agents. These agents cooperate to identify the causes of anemia at cats. The paper presents a tentative development methodology for cooperating expert systems.

The paper [15] presents a self-organizing medical diagnosis system, mirroring swarm intelligence to structure knowledge in holonic patterns. The system sets up on an alliance of agents specialized in medical diagnoses that self-organize in order to provide a viable medical diagnosis.

3. Contract net protocol

Systems that operate in isolation cannot solve many difficult *problems* (*tasks*). These problems solving require the cooperation of more systems with different [16, 17] *capabilities* and *capacities*. The *capability* of a system consists in the *specializations* detained by the system. A specialization describes a problem solving [3]. The *capacity* of a system consists in the amount of problems that can be solved by the system using the detained resources. The agents represent systems with characteristics like: increased autonomy in operation, communication and cooperation capability with other systems. The systems composed from more agents are called *multiagent systems*. The *contract net protocol* represents a cooperative problem solving which can be used in distributed multiagent systems [1, 2, 3, 4, 5]. The contract net problem allocation protocol allows agents to cooperatively allocate their problems to other agents with capability, capacity and opportunity to successfully carry them out. The contract net protocol is an interaction protocol for cooperative problem solving among agents, providing a solution for the so-called connection problem "finding an appropriate agent to work on a given problem".

A problems allocation task can be described as follows:

$$< PR, A, f >,$$
$$f : PR \rightarrow P(A),$$
$$\forall p \in PR, \exists A' \subseteq A, where f(p) = A'.$$

The set $PR = \{p_1, p_2, \ldots, p_k\}$ represents the overtaken problems from the user which must be solved. The set $A = \{a_1, a_2, \ldots, a_n\}$ represents the agents which can solve problems. The function f associates to each problem the agents that will solve the problem. A' represents the agents that will solve the problem p.

Because of the distributed nature, dynamism and heterogeneity of many multiagent systems the contract net protocol is frequently used for problem allocation to the agents. As an example of application of the contract net protocol, we mention the use of the contract net protocol in a TRACE multiagent system [5]. A TRACE multiagent system is composed from more organizations of agents. The contract net protocol is used in each organization for problem allocation to solving.

As examples of disadvantages of the contract net protocol used in a multiagent system we mention [18]: the overloading of the network with data transmissions and decreased coherence in the functioning of the multiagent system. Practical analysis of the efficiency and scalability of the contract net protocol are carried out in the paper [19].

4. Expert system agents, assistant agents

We propose the endowment of the expert systems with agents' capabilities, we name the agents obtained these way *expert system agents* [17]. The expert system agents can solve in a more flexible way a larger variety of problems than the traditional expert systems. The expert system agents can be endowed with medical diagnosis capability.

As examples of advantages of the expert system agents as opposite to the traditionally used expert systems we mention:

- the expert system agents can perceive and interact with the environment. They can learn and execute different actions in the environment autonomously;

- the expert system agents can communicate with other agents and humans, which allows the cooperative problem solving.

The *knowledge-based agents* can assist the medical specialists (physicians, expert system agents specialized in medical diagnosis) in the problem solving processes [17].

As examples of assistance that can be offered by an assistant agent to a medical specialist (artificial and human) we mention:

- the specialist can solicit the assistant agent help in solving of some subproblems of the overtaken problem. This cooperating way allows the problems solving faster;

- the assistant agent can verify the correctitude of the problems solutions obtained by the specialist. The specialist and the assistant agent can solve the same problem simultaneously using different problem solving methods. The assistant agent knows which problem is solved by the specialist, and can solve the problem using the problem solving specialization with which is endowed. The same solution obtained by the assistant agent and the specialist increases the certitude in the correctitude of the obtained problem solution;

- the assistant agent can analyze details that are not observed by a physician. As an example, we mention the suggestion to use a medicine without analyzing some important contraindications of the medicine.

5.The proposed medical diagnosis system

A medical diagnosis problem consists in the description of one or more illnesses. The solution of the problem represents the identified illness or illnesses. A person may have more illnesses each of them with specific symptoms. A problem solving whose solution is more illnesses require knowledge from more medical domains. The symptoms of more illnesses may have some similarities, which make the difficult identification of them. In the case of some illnesses, the causes of the illnesses are not known. A medicine to an illness may have different effects at different persons that suffer from the illness. The symptoms of the same illness may be different at different persons.

Some difficult diagnosis problems cannot be solved by a physician or an expert system specialized in medical diagnosis that operates in isolation. In this paper, we propose a cooperative medical diagnosis system for difficult medical diagnosis problems solving. We consider the problems who's solving require knowledge from more medical domains. The cooperative solving of the medical diagnosis problems by the proposed system is partially based on the cooperative problem solving using the contract net protocol [1, 2, 3, 4, 5] and the general cooperative problem solving described in the paper [6].

The proposed heterogeneous medical diagnosis system is composed from a set $MDS = MD \cup AS$ of members. Where $MD = \{md_1, md_2, \ldots, md_n\}$ represent the agents specialized in medical diagnosis and $AS = \{as_1, as_2, \ldots, as_k\}$ represent the assistant agents. In the following, we name all the members (artificial and human) of the diagnosis system *agents*. As examples of agents specialized in medical diagnosis that can be members of the multiagent system, we mention: the physicians and the expert system agents specialized in medical diagnosis. As examples of artificial assistant agents, we mention the

Internet agents and robots. An Internet agent may collect knowledge from distributed knowledge bases. As example of knowledge, which can be collected by an Internet agent, we mention the description of the symptoms of an illness. Assistant robots can realize different medical analyzes. As examples of human assistants, we mention the medical assistants.

Each agent member of a multiagent system has [16, 17] problems solving capability and capacity. The capability of an agent consists in the specializations of the agent. An agent AG is endowed with a specialization set $SP = \{S_1, S_2, \ldots, S_k\}$. The specializations set of an agent can be different from the specializations set of the other agent. If the agent AG_i is endowed with the specializations set SP_i, there may exist an agent AG_j with the specializations set SP_j, where $SP_i \neq SP_j$. Each agent can be endowed with a limited number of specializations [3]. The agents from the set MD have different specializations sets in medical domains. The agents from the set AS have different specializations sets that allow the assistance of the agents from the set MD. The capacity of an agent consists in the amount of problems that can be solved by the agent. An agent may overtake for solving more problems.

A medical diagnosis problem solving may require more specializations that must be applied consecutively. After the application of a specialization in the solving of the problem a result (a new problem) is obtained, the result can be processed using another specialization obtaining a new result. This recursive process continues until the problem solution is obtained.

5.1. The agents operation

In the following, we analyze how an agent specialized in medical diagnosis from the set of agents MD member of the proposed diagnosis system operates. A medical diagnosis problem transmitted to the multiagent system is received by an agent specialized in medical diagnosis. The *Algorithm Agent Operation* describes briefly how an agent AG proceeds when it receives a problem. The agent who receives the problem may process the problem the obtained result is transmitted to another agent. The recursive process of transmitting the problem results from agent to agent continues until an agent solves the problem. The agent who obtains the problem solution transmits the solution to the sender of the problem. This agent can realize some verifications of the correctitude of the obtained problem solution. This recursive process of replaying the problem solution continues until the problem solution is received by the agent who has received the initial problem from the patient. This agent will return the problem solution to the patient. If an agent can't process an overtaken problem than the agent must transmit the problem in the received form to a suitable agent. All the members of the medical diagnosis system solve the diagnosis problems cooperatively. In the multiagent system each agent specialized in medical diagnosis can receive problems. The specializations necessary to a problem solving and the order in which they must be applied are not specified in advance.

Algorithm agent operation

Step 1.

The agent AG overtakes the problem P.

Step 2.

The agent AG estimates the necessary specialization to the problem solving and the order in which the specializations must be applied to solve the problem. Let $S = < S_1, S_2, \dots, S_n ... >$ be the estimated specializations necessary in the problem solving.

Step 3.

If (AG can process the problem P) *then* {

The agent AG establishes the firsts' specializations $S' = < S_1, S_2, .., S_j >$ that can use in the problem solving (it has the necessary capacity and capability).

The agent AG processes the problem P using the specializations from S' in the specified order. Let P' be the obtained result.

$$P(S_1) \Rightarrow P_2(S_2) \Rightarrow ... \Rightarrow P_j(S_j) \Rightarrow P'.$$

If $(S = S')$ *then*

{

"The received problem P is solved. P' represents the problem solution."

Goto Step 6.

}

else

The agent AG transmits the problem P' announcement AN to some agents members of the multiagent system.

$$AN =< P'; S_{j+1}, \ldots, S_n..; \mathit{Parameters1} > .$$

}

else

The agent AG transmits the problem P announcement AN to some agents members of the multiagent system.

$$AN =< P; S_1, \ldots, S_n..; \mathit{Parameters2} > .$$

Step 4.

While (the waiting time to the problem announcement AN is not expired) *do*

The agent AG receives and evaluates bids to the announcement AN.

The agent AG awards the problem to a suitable agent C.

Step 5.

The agent AG receives the result PS (the obtained problem solution) from the agent C. If is necessary can process the result PS.

Step 6.

The obtained solution is verified and transmitted to the problem P sender.

End.

A problem announcement AN has the following form:

$$AN =< PR; SP; PAR > .$$

Where: PR represents the transmitted problem, SP represents the estimated medical specializations list necessary to the problem PR solving (there is a list of specializations that must be applied in the specified order from the list), PAR represents different transmitted information. As examples of information contained in the PAR list, we mention: eligibility specification, bid specification, and expiration time. The eligibility specifies the criteria of the bid acceptance. As example of eligibility criteria, we mention: a higher specialization in the PR diagnosis problem solving (the patient illness is difficult to identify). The bid specification tells to the contacted agents what information must be provided with the bid. Returned bid specifications gives to the announcement sender agent a basis for comparing bids received from different agents. As an example, of information that can be provided with the bid specification, we mention the problem solving time. The expiration time is the deadline for receiving bids.

A response R of an agent AG_i to the problem announcement AN has the following form:

$$R =< AD, AN, Offer, Capability, Capacity, SPEC, Relevance > .$$

Where: AD represents the agent AG_i address, AN represents the announcement identifier, *Offer* represents the bid to the problem solving (acceptance or rejection), *Capability* represents the capability of the agent AG_i (the specializations which can use the agent AG in the problem solving). As an example, an expert system can be endowed with specializations in more medical domains detained in different knowledge bases. *Capacity* represents the processing capacity of the agent AG_i. $SPEC$ represents the estimated specializations by the agent AG_i, necessary in the problem solving specified in the announcement AN. An agent cannot establish always all the specializations necessary to a problem solving precisely, some identified necessary specializations may be absent or incorrect. Each agent is limited in knowledge. When an agent receives the bids to a problem announcement, using the specializations specified in the response, it can evaluate if it had made mistakes in the necessary specializations estimations, and if it is necessary, it can modify the specializations list (it can change specializations from the list, it can add new specializations or it can change the order of the specializations). When an agent transmits a problem to be solved to an agent then transmits the new specializations list. In the determination of the necessary specializations on the base of the received response to a problem announcement the agent can use the information contained in the *Relevance* lists of the received responses. The Relevance list values describe how precise is the estimated necessary specializations list. As an example, an agent that has a specialization can estimate more precisely a problem whose solving requires the specialization, than an agent that does not have the specialization. A cardiologist physician can identify with a higher accuracy a cardiology related illness than a physician specialized in general medicine.

Each agent specialized in medical diagnosis can receive diagnosis problems and diagnosis problems announcements. Each agent can solve problems corresponding of his specialization set. Different agents solve each overtaken problem step-by-step using different specializations. An agent who overtakes a problem may require the help of other agents in solving parts of that problem. The agents from the set MD may require the assistance of the agents' members of the set AS. Different ways in which the assistant agents can assist the agents specialized in medical diagnosis's in the problem solving processes are enumerated in the section 3. As an example of assistance, an expert system agent can require to a human medical assistant the realization of some medical analysis necessary in increasing the accuracy in identification of an illness. An assistant interface agent can assist a physician in the communication with artificial agents. As examples of assistance offered by an interface agent to a physician we mention: the translation of the information communicated by artificial agents specialized in medical diagnosis to the physician into an understandable form to the physician, the indication of the agents that has a medical specialization, the indication of the assistant agents that has a specialization, the indication of the human and artificial agents.

For the representation of the transmitted informations, the agents (human and artificial) must use the same *knowledge representation language* and must share the same *ontology* (dictionary of the used terms). The notions of knowledge representation language and ontology are defined in the paper [4].

The diagnosis system can operate without replaying a problem results to the problem sender agent. The results replaying are described in the Algorithm Agent Operation in the steps: *Step 5* and *Step 6*. In this case, if an agent obtains the final diagnosis problem solution (it is not necessary to realize new medical analyses) then transmits the solution to the sender of the problem (the patient). If the diagnosis system operates in this way, when an agent awards another agent with a problem then transmit the patient address.

5.2. A medical diagnosis problem solving

In the following, we present an example which illustrates how the proposed diagnosis system solves an overtaken problem (the *Step 5* and *Step 6* from the algorithm are not used). We consider a diagnosis system formed from the following agents: ag_g, ag_c, ag_u. Where: ag_g represents an expert system agent specialized in general medicine, ag_c represents a doctor specialized in cardiology, ag_u represents a doctor specialized in urology.

As an example, we consider the problem P (the patient suffer from two illnesses, a cardiology and urology related illness).

$$P = \{\text{description of a cardiology related illness, description of an urology related illness}\}.$$

The problem solving requires the specialization set $SPEC$.

$$SPEC =< S_i, S_j, S_k > .$$

Where: S_i represents a specialization in general medicine, S_j represents a specialization in cardiology (the specialization of a cardiologist doctor), S_k represents a specialization in urology (the specialization of an urologist doctor).

The solution SOL of the problem that must be obtained represent the identified two illnesses of the patient.

$$SOL = \{\text{the identified cardiology related illness, the identified urology related illness}\}.$$

Processing the problem P using the specialization S_i by the agent with the specialization in general medicine, the result (new problem) P_i will be obtained. Processing P_i using the specialization S_j in cardiology the result P_j will be obtained. Processing P_j using the specialization S_k in urology the result SOL will be obtained, where SOL represents the solution of the problem (the two identified illnesses).

The problem P solving process using the specializations S_i, S_j, S_k consecutively can be described as follows:

$$P(S_i) \Rightarrow P_i(S_j) \Rightarrow P_j(S_k) \Rightarrow SOL.$$

The result P_i represents the patient illnesses symptoms and the observations elaborated by the agent specialized in general medicine related to the patient illnesses. The result P_j represents the identified cardiology related illness of the patient identified by the agent specialized in cardiology, the patient illnesses symptoms and the observations elaborated by the agent specialized in general medicine. The result SOL represents the identified two illnesses of the patient, the urology related illness is identified by the agent specialized in urology.

In the following, we present a simplified scenario that illustrates how the problem P is solved by the diagnosis system. We consider that the patient transmits the problem P to the agent specialized in general medicine ag_g.

$$patient(P) \Rightarrow ag_g.$$

The agent ag_g process the problem P using its specialization S_i obtaining the result P_i.

$$ag_g(P) \rightarrow P_i.$$

The agent ag_g announce the problem P_i to the members of the multiagent system. ag_g does not suppose any illness of the patient (does not indicate any specialization necessary in the problem P_i processing).

$$ag_g(P_i) \Rightarrow ag_c.$$
$$ag_g(P_i) \Rightarrow ag_u.$$

The agents ag_c and ag_u answer to the problem P_i announcement. They indicate in their response the supposed necessary specializations S_j and S_k in the following processing's. Both agents indicate their capability (specializations) which can be used in processing the problem P_i.

$$ag_g \Leftarrow ag_c(S_j).$$
$$ag_g \Leftarrow ag_u(S_k).$$

The agent ag_g select the agent ag_c and transmits the problem P_i to the agent ag_c.

$$ag_g(P_i; S_j, S_k) \Rightarrow ag_c.$$

The agent ag_c process the problem P_i obtaining the result P_j.

$$ag_c(P_i) \rightarrow P_j.$$

The agent ag_c announce the problem P_j to the agents' members of the multiagent system.

$$ag_c(P_j; S_k) \Rightarrow ag_g.$$
$$ag_c(P_j; S_k) \Rightarrow ag_u.$$

The agent ag_u answers to the announcement.

$$ag_c \Leftarrow ag_u(S_k).$$

The agent ag_c transmits the problem to the agent ag_u.

$$ag_c(P_j; S_k) \Rightarrow ag_u.$$

The agent ag_u solves the problem obtaining the solution SOL.

$$ag_u(P_j) \rightarrow SOL.$$

The solution SOL is transmitted to the patient by the agent ag_u.

$$ag_u(SOL) \Rightarrow patient.$$

5.3. Advantages of the proposed diagnosis problem solving

The proposed medical diagnosis system can be more efficient in the difficult diagnosis problem solving than the physicians and the expert systems that operates in isolation. The proposed multiagent system can solve difficult medical diagnosis problems using efficiently the agents' (artificial and human) capabilities and capacities. The specializations necessary to a problem solving are not specified in advance, the agents must discover cooperatively the specializations necessary to the problem solving and the order in which they must be applied. The specializations necessary to a problem solving may be distributed between different agents.

It is not necessary to a problem sender to know to which agent send the problem. The problem is sent to an agent, in the following the problem is solved step-by-step, at each step is chosen the best agent who can process the results. The diagnosis system can solve randomly transmitted problems to the agents.

If an agent, it is not sure about the correctitude of the obtained result can send the problem to an agent with the same specialization. The same results of the same problem obtained by more agents increase the certitude in the correctitude of the obtained solution. The accuracy in detecting the same illness by different agents with the same specialization may be different. As an example a physician specialized in cardiology after solving a cardiology related illness problem, can transmit the same problem to an expert system agent specialized in cardiology. The same solution obtained by the expert system agent as the physician increase the certitude in the correctitude of the identified illness.

The agents' members of the medical diagnosis system can be endowed with new specializations. The inefficient specializations can be eliminated or improved. In the diagnosis system can be added new agents, the inefficient agents can be eliminated. The adaptation of a system with more members many times is easier than the adaptation of a system that operates in isolation that solves the same problems [17].

The agents' members of the diagnosis system can learn autonomously from each other during the problems solution-replaying processes (the steps: *Step5* and *Step6* described in the *Algorithm Agent Operation*). When an agent receives a replayed problem solution, the agent also has the problem description (the illness symptoms) and the partial solutions obtained by the agents who processed the problem during the problem solving. In this way, the agent can learn new medical diagnosis problems solving or can improve the existent diagnosis's accuracy. As examples, an agent may: learn new symptoms of an illness, increase the accuracy in the identification of a specialization necessary to an illness processing, memorize the assistant agents whose help can require during different problems processing.

6. Conclusions

The medical diagnosis elaboration by a physician or an expert system may have many difficulties. We propose the endowment of the expert systems with agents' capabilities we name this agents expert system agents. Expert system agents can be endowed with medical diagnosis problem solving capabilities. Knowledge based agents can be endowed with capability to assist the agents (physicians, expert system agents, etc.) specialized in medical diagnosis in the diagnosis problem solving processes.

In this paper, we have proposed a new cooperative heterogeneous medical diagnosis system composed from agents (human and artificial) specialized in medical diagnosis and assistant agents (human and artificial). The cooperative problem solving by the proposed diagnosis system combine the human and artificial systems advantages in thinking (in the problems solving). The humans can elaborate decisions using their knowledge and intuition. The intuition allows the decision elaboration without the use of all the necessary knowledge, in this way sometimes can be solved problems for which doesn't exists elaborated solving methods. The artificial thinking allows the problems solving based on existent problem solving methods verifying many conditions.

This way artificial systems can solve some times the problems more precisely than the humans.

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Barna Iantovics
Department of Computer Science
Petru Maior University of Tg. Mures
Str. Nicolae Iorga, Nr.1 Tg.-Mures, Romania, 540088
e-mail:*ibarna@davos.science.upm.ro*