A NOVEL DIAGNOSIS SYSTEM SPECIALIZED IN DIFFICULT MEDICAL DIAGNOSIS PROBLEMS SOLVING

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ABSTRACT

The purpose of the study consists in the development of a medical diagnosis system capable of solving difficult diagnosis problems. In this paper, we propose a novel medical diagnosis system. The medical diagnosis system is a heterogeneous system with human and artificial agents members specialized in medical diagnosis and assistant agents. The proposed diagnosis system can solve difficult medical diagnosis problems that cannot be solved by doctors or artificial systems specialized in medical diagnoses that operate in isolation. The problem solving by the diagnosis system is partially based on the blackboard-based problem solving.

1. Introduction

In the medical domains, many medical diagnosis systems that operate in isolation or cooperate are proposed and used [8, 1, 10, 2, 12, 14, 9, 11, 4]. The paper [12] describes the state of the art medical information systems and technologies at the beginning of the 21st century. The complexity of construction of full-scaled clinical diagnoses is also analyzed as the basis of medical databases. In the following, we enumerate some medical diagnosis systems.

Various diagnosis technologies are studied and used. It is necessary to develop automatic diagnosing processing systems in many medical domains. The paper [9] presents a cardiac disease analyzing method using neural networks and fuzzy inferences.

The paper [1] analyzes different aspects of the multiagent systems specialized in medical diagnosis. The understanding of such systems needs a high-level visual view of the systems' operation as a whole to achieve some application related purpose. The paper analyzes a method of visualizing, understanding, and defining the behaviour 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 [8] proposes 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 [2] 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 diagnosis in specialized medical domains.

The paper [11] 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.

The paper [14] presents a cooperating expert system called 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 [4] presents a cooperating heterogeneous multiagent system specialized in medical diagnoses. The diagnosis system is composed from human and artificial agents. The knowledge necessary to an overtaken diagnosis problem solving is not specified in advance. The members of the diagnosis system must discover cooperatively the problem solving.

2. Assistant agents, expert system agents

Systems that operate in isolation cannot solve many difficult *problems* [3, 13, 5]. These problems solving require the cooperation of more systems with different [6] *capabilities* and *capacities*. The *capability* of a system consists in the *specializations* detained by the system. A *specialization* is a problem solving method [3]. The *capacity* of a system consists in the amount of problems that can be solved in deadline by the system using the detained resources. The capacity of a system defines the quantity of resources that can be used in the problems solving. The *agents* represent systems with proprieties like: increased autonomy in operation, capability of

communication and cooperation with other systems. In the following, we call *agents* the humans and the artificial systems with agents' capabilities. The systems composed from more agents are called *multiagent systems*.

Expert systems can be endowed with medical diagnosis capability. We propose the endowment of the expert systems specialized in medical diagnosis with agents' capabilities. We call these agents, *expert system agents* [6]. Expert system agents can solve a larger variety of problems in a more flexible way than the traditional expert systems.

As examples of the advantages of the expert system agents as opposed to the 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 or humans, which allows the cooperative problem solving.

The *knowledge-based agents* can be endowed with capabilities to assist the agents (human and artificial) specialized in medical diagnosis in the problem solving processes [6]. We call the agents mentioned before *assistant agents*.

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

- the assistant agent can analyze details that are not observed by a doctor. For example, we mention the suggestion of a doctor for a patient to use a medicine without analyzing some important contraindications of the medicine;
- the assistant agent can verify the correctitude of a problem's solution obtained by the specialist. The assistant agent knows the problem that is solved by the specialist. This way, the specialist and the assistant agent can solve the same problem simultaneously using different problem solving methods. For example, a doctor specialized in cardiology and an assistant expert system agent specialized in cardiology can try to identify simultaneously a cardiology related illness. The same solution obtained by the assistant agent and the medical specialist increases the certitude in the correctitude of the obtained solution. The accuracy in detecting the same illness by different agents may be different;
- the specialist can require the assistant agent's help in solving subproblems of an overtaken problem. This cooperation allows faster the problem solving.

3. 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. The symptoms of more illnesses may have some similarities, which make their identification difficult. The symptoms of the same illness may be different at different persons. 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.

In this paper, we propose a cooperative heterogeneous medical diagnosis system for difficult medical diagnosis problems solving. Some difficult medical diagnosis problems cannot be solved by a doctor or an expert system agent that operates in isolation [5]. In many medical diagnosis problems solving knowledge from more medical domains have to be used. The problem solving by the proposed diagnosis system is partially based on the *blackboard-based problem solving* [7, 13]. Figure 1 illustrates the proposed medical diagnosis system.

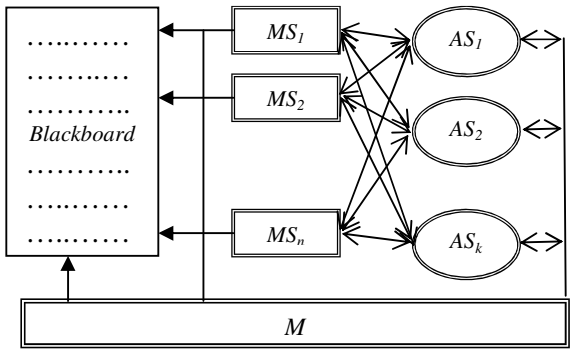

Figure 1. The proposed medical diagnosis system

The proposed medical diagnosis system *MDS* is composed from a set of *agents*.

$$MDS = MS \cup \{M\} \cup AS.$$

$MS = \{MS_1, MS_2, \ldots MS_n\}$ represent agents (human and artificial) specialized in medical diagnosis called *knowledge sources.* As examples of knowledge sources, we mention: the doctors and the expert system agents. *M* represents a doctor called *moderator*. $AS = \{AS_1, AS_2, \ldots AS_k\}$ represent the assistant agents (human and artificial). The artificial assistant agents are knowledge-based agents. As examples of artificial assistant agents, we mention the Internet agents and the assistant robots. An Internet agent may collect knowledge from distributed knowledge bases. As an example of knowledge that 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. As an example of assistance, an expert system agent can require from a human medical assistant the realization of some medical analysis necessary in increasing the accuracy in the identification of an illness. An assistant interface agent can assist a doctor in the communication with the artificial agents. As examples of assistance offered by an interface agent to a doctor, we mention: the

translation of the knowledge communicated by artificial agents specialized in medical diagnosis into an understandable form to the doctor, the indication of the assistant agents that has a specialization, the indication of the human and artificial agents.

The agents' members of the diagnosis system have different capabilities. Each agent is endowed with a specialization set $SP = \{S_1, S_2, \dots S_k\}$. An agent can be endowed with a limited number of specializations [3, 6]. Each knowledge source is specialized in some aspects of the problems solving that can be solved by the diagnosis system. The knowledge sources have different specializations sets in medical domains. The moderator is specialized in the coordination of the problems solving. The agents from the set *AS* have different specializations sets that allow the assistance of the agents from the set $MS \cup \{M\}$. 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 $SP_i \neq SP_j$.

The algorithm *Problem Solving* describes how the knowledge sources and the moderator solve an overtaken medical diagnosis problem at a problem solving cycle.

Algorithm - Problem Solving

The problem *P* that has to be solved is written onto the blackboard.

While ((the problem is not solved) *and* (the problem solving can continue)) *do*

{

- Each knowledge source watches the blackboard and sends a message to the moderator that contains the specification of its capability and capacity to process the result from the blackboard.
- The moderator using the knowledge contained in the received messages from the knowledge sources choose the best-fitted knowledge source MS_i capable to process the result from the blackboard.
- The moderator allows the writing right to the selected knowledge source MS_i.
- The knowledge source MS_i processes the result from the blackboard. The obtained result is written onto the blackboard.
- After the knowledge source MS_i finishes the result processing, the moderator retracts the writing right from the knowledge source MS_i.

}

End.

A problem solving cycle consists in overtaking and solving a problem. The problem is solved onto a *blackboard*. The blackboard represents a memory shared by all the members of the diagnosis system. A problem solving begins when the problem is written onto the blackboard. The knowledge sources watch the blackboard, looking for an opportunity to apply their expertise to develop the solution. When a knowledge source finds sufficient information to contribute, he records the contribution onto the blackboard. This additional information may enable other knowledge sources to apply their expertise. This process of adding contributions to the blackboard continues until the problem is solved or the problem cannot be solved. The moderator supervises the problem solving process. The assistant agents may assist the knowledge sources and the moderator during their operation. All the members of the medical diagnosis system solve the diagnosis problem cooperatively.

The announcement, in which a knowledge source MS_i specifies how it can contribute to a problem solving, has the following parameters:

<*Capability*, *Capacity*, *Relevance*>.

Capability represents the capability of the agent MS_i (the specialization that can use MS_i in the problem processing). *Capacity* represents the processing capacity of MS_i (the problem processing time). *Relevance* specifies the estimated importance of the processing that can be realized by MS_i (the measure in which the processing approaches the problem solution).

The artificial software agents can access the content of the blackboard (memory). The humans can view the content of the blackboard via output devices. Only the knowledge sources can write onto the blackboard. The writing onto the blackboard consists in adding, changing or retracting knowledge from the blackboard. A knowledge source can write onto the blackboard if it has writing right. The right for the knowledge sources to write onto the blackboard is allowed and retracted by the moderator. In the selection of the best-fitted knowledge source to process a problem result, the moderator uses the informations contained in the announcements parameters.

As examples of the knowledge that can be added onto the blackboard by a knowledge source at a problem solving cycle we mention:

- the results of some medical analysis;
- a new illness. The knowledge source supposes that the patient has an illness;
- new questions that must be answered by other knowledge sources. The knowledge source is limited in knowledge, he is specialist in a certain medical domain;
- new questions that must be answered by the patient.

As examples of the knowledge that can be eliminated from the blackboard by a knowledge source at a problem solving cycle, we mention:

- useless informations. Some information written onto the blackboard are not relevant in the diagnosis process;
- a supposed illness. The knowledge source demonstrates that the patient does not have the supposed illness written onto the blackboard.

As examples of the knowledge that can be modified onto the blackboard by a knowledge source at a problem solving cycle, we mention:

- the knowledge that is changed in time. Some medical analysis results are changing in time (a

diagnosis process may have a longer duration). Some patients do not describe correctly the symptoms of their illness.

The artificial agents can write directly onto the blackboard. If a doctor wants to write onto the blackboard, than he can transmit the knowledge to an artificial agent that will write the transmitted knowledge onto the blackboard. The knowledge from the blackboard must be understandable to all the members of the diagnosis system (human and artificial). For the representation of the knowledge written onto the blackboard, the agents 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 papers [13, 3].

4. An example of a problem solving

In the following, we present a scenario that illustrates how a proposed medical diagnosis system *MDS* solves an overtaken medical diagnosis problem *P* (the patient suffers from two illnesses, a cardiology and an urology related illness).

P = <description of a cardiology related illness, description of an urology related illness>.

$$MDS = \{AGg, AGc, AGu\} \cup \{M\} \cup \{ASi\}.$$

AGg, *AGc* and *AGu* represent the knowledge sources. *AGg* represents an expert system agent specialized in general medicine. *AGc* represents a doctor specialized in cardiology. *AGu* represents a doctor specialized in urology. *M* represents a moderator doctor specialized in the coordination of the problem solving. *ASi* represents an assistant agent specialized in information search about the patients in distributed databases.

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

SOL = <the identified cardiology related illness, the identified urology related illness>.

In the following, we describe step by step the scenario of the overtaken problem *P* solving by the medical diagnosis system *MDS* using the cooperative problem solving described in the previous section.

Problem solving

Step 1

- The problem *P* is written onto the blackboard.

Step 2

- Each knowledge source watches the blackboard.
- *AGg* requires the assistance of *ASi* in obtaining the description of the patient's prior illnesses. *ASi* transmits the required information to *AGg*.

Step 3

- Each knowledge source announces its capability and capacity to contribute to the problem *P* processing.
- *M* based on the announcements parameters values chooses the best-fitted knowledge source. Let *AGg* be the selected knowledge source (the contribution of *AGg* is the most relevant, *AGg* can write onto the blackboard the patient's prior illnesses and different observations related to the patient's current illnesses).
- *M* allows the writing right to *AGg*.
- *AGg* processes the problem *P* obtaining the result *P1* (*P1* represents a new problem) that is written onto the blackboard.
- *M* retracts the writing right from *AGg*.

Step 4

- Each knowledge source announces its capability and capacity to contribute to the problem *P1* processing.
- *M* chooses the best-fitted knowledge source capable to contribute to the problem *P1* solving. Let *AGc* be the selected knowledge source (*AGc* can establishes the patient's cardiology related illness).
- *M* allows the writing right to *AGc*.
- *AGc* processes the problem *P1* obtaining the result *P2* that is written onto the blackboard.
- *M* retracts the writing right from *AGc*.

Step 5

- Each knowledge source announces its capability and capacity to contribute to the problem *P2* processing.
- *M* chooses the best-fitted knowledge source *AGu* capable to contribute to the problem solving (*AGu* can establishes the patient's urology related illness).
- *M* allows the writing right to *AGu*.
- *AGu* processes the problem *P2* obtaining the solution *SOL* that is written onto the blackboard.
- *M* retracts the writing right from *AGu*.

End.

The problem *P* solving process can be described as follows:

$$AGg\ (P) \Rightarrow AGc\ (P1) \Rightarrow AGu\ (P2) \Rightarrow SOL.$$

The result *P1* represents the patient illnesses symptoms, the descriptions of the patient's prior illnesses and different general observations related to the patient's current illnesses elaborated by *AGg*. The result *P2* represents the cardiology related illness of the patient identified by *AGc*, the symptoms of the patient's illnesses, the description of the patient's prior illnesses and different general observations related to the patient's current illnesses elaborated by *AGg*. The result *SOL* represents the identified two illnesses of the patient. The urology related illness is identified by *AGu*.

5. Advantages of the proposed diagnosis system

The elaboration of a medical diagnosis by a doctor or an expert system that operates in isolation may have many difficulties [5]. Many difficult medical diagnosis problems solving require cooperation in their solving. The main advantage of the proposed medical diagnosis

problem solving consists in the solving of difficult diagnosis problems, whose solving require knowledge from different medical domains. The problems solving specializations in the diagnosis system are distributed between the systems' member agents (human and artificial). The knowledge necessary to the diagnosis' problems solving are not specified in advance, the diagnosis system members must discover cooperatively the problems solving.

The problems solving difficulty is distributed between the agents members of the diagnosis system. Each knowledge source can use its specializations in certain circumstances, when it finds knowledge on the blackboard that can process. The moderator is responsible to decide which knowledge source will overtake a problem result processing at a moment of time. A knowledge source can require the help of assistant agents. This way, the problem solving difficulty is distributed between the knowledge source and the assistant agents who help it.

The artificial agents' members of the medical diagnosis system can be endowed with new specializations. The inefficient specializations can be eliminated or improved. The adaptation of a cooperative multiagent system in the efficient solving of a problem many times is easier than the adaptation of an agent that solves the same problem [13, 3, 6]. New agents can be added in the diagnosis system, the inefficient agents can be eliminated.

6. Conclusions

We propose the endowment of the expert systems with agents' capabilities. We call these agents expert system agents. Knowledge-based agents can be endowed with the capability to assist the agents (doctors, expert system agents) specialized in medical diagnosis in the diagnosis problem solving processes. In this paper, we have proposed a novel 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 agents advantages in the problems solving. The humans can elaborate decisions using their knowledge and intuition. The intuition allows the elaboration of the decisions without the use of all the necessary knowledge, this way sometimes problems for which does not exists elaborated solving methods can be solved. The artificial thinking allows the problems solving based on existent problem solving methods sometimes verifying many conditions. This way, the artificial agents can solve many times the problems precisely, verifying conditions that can be ignored by the humans.

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