Cooperative Medical Diagnoses Elaboration by Physicians and Artificial Agents

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Summary. Cooperative medical diagnosis systems seem to be well suited for the solving of many difficult medical diagnosis problems, like the combinations of illnesses where between the illnesses treatments are dependencies. The solving of many difficult medical problems requires knowledge from different medical domains, which cannot be detained by a single physician or a medical computational system. In this paper, a novel medical multiagent system called MASM (Medical Assistant Multiagent System) that can help physicians in their work is proposed. Are analyzed advantages of the cooperative problems solving by physicians and the proposed multiagent system. By cooperation, the human and artificial thinking advantages in the diagnostics elaboration are combined. The proposed multiagent system is a complex system. It is composed from relatively simple agents, which can discover cooperatively emergent properties that arise during the medical problems solving processes that can be ignored by the physicians. Discovered informations allows to the MASM system to increase the accuracy of the elaborated diagnostics and reduce the complexity of the diagnosis processes.

Keywords: complex system, emergent proprieties in artificial systems, software agent, expert system agent, knowledge-based system, diagnostic accuracy, medical diagnosis system, expert system

1 Introduction

Many medical diagnosis problems solving is a difficult task, which require the contribution of more medical human specialists and medical computational systems. Some difficult diagnostics elaboration requires a planning process to that must contribute more physicians with different medical knowledge. For example, we mention the planning of a surgery intervention for the elimination of a huge tumor. Such planning process can require the analysis of different situations that can occur during the treatment application (for example, the loss of a huge quantity of blood). To this problem solving must contribute more human medical specialists. Assistant agents can be useful in such diagnostics establishment. They can verify different medical hypothesis, established autonomously by them or required by physicians. Such analyses results may allow the detection of mistakes that may appear in the physicians decisions. For example, we mention the suggestion of a medicine for treating a patient's illness in the situation when the patient is allergic to that medicine. Another possible application of the assistant agents, consist in the intelligent mediation of the physicians cooperation during different medical tasks fulfilling, which can make easier the diagnoses elaborations by the physicians (the physicians must verify less informations and data, they also may have more certitude in some elaborated medical hypotheses correctness). Many times is required for the assistant agents to cooperate with other agents in order to handle the requirements that they must fulfill.

In this paper, a novel assistant multiagent system called *MASM* (*Medical Assistant Multiagent System*) is proposed. The proposed multiagent system is a complex system, composed from relatively simple agents called *assistant expert system agents* that cooperatively can help physicians in their work. Assistant expert system agents represent a novel class of agents developed in our previous researches. Another novelty in the proposed *MASM* system consists in the novel cooperative assistance of the physicians in the medical problem solving processes offered by the system. The intelligent cooperative assistance partially hide the complexity of the medical diagnosis problems to the physicians, making easier the fulfilling of some medical tasks by them, and increasing the accuracy of the elaborated diagnostics. A physician interacts directly only with an owned assistant agent member of the system. Each assistant agent will cooperate during the problems solving, if is necessary with other assistant agents' members of the system. For a physician is necessary to knows only its owned assistant agent, the rest of the system's member agents are hidden to him. Each assistant agent know how must cooperate with different agents to offer the necessary help to its owner physician. The system's members cooperate in order to handle the complexity of the problems solving. They can discover cooperatively emergent properties that arise during the medical problem solving processes. Discovered proprieties may allow to the *MASM* system to improve the effectiveness of the medical problem solving processes. The proposed assistant multiagent system cannot substitute the physicians, but the cooperative problems solving with the physicians, may increases the accuracy of the elaborated medical diagnostics by the physicians. The final diagnostic establishment and validation in the case of an illness is the responsibility of a physician.

The paper is structured as follows: in Section 2 are presented agents and multiagent systems used for medical problems solving; Section 3 describes previous researches related with the *MASM* multiagent system; in Section 4 the novel *MASM* multiagent system is described; Section 5 presents the conclusions of the paper.

2 Agent-based medical systems

The *capability* of a cognitive system consists in the problem solving *specializations* detained by the system [1, 4]. The *capacity* of a cognitive system consists in the amount of problems that can be solved in deadline by the system using the detained resources [1, 4]. *Agents* represent artificial systems with properties, like [2]: increased autonomy in operation, capability of communication and cooperation with other systems. The systems composed from more agents are called *multiagent systems* [1, 2, 3, 4]. The solving of many difficult problems, require the cooperation of more agents with different [2] capabilities and capacities, which motivate the use of multiagent systems versus the use of agents that operate in isolation.

Agents and multiagent systems can be endowed with medical knowledge. Many medical agents that can cooperate with physicians and other agents are proposed and used [5, 6, 7, 8, 9, 10, 11, 12, 13, 36]. The paper [9] 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. In the medical domain many type of medical problems can be solved by human medical specialists, which uses medical computational systems some times agent based medical systems [30]. As examples of problems, which appear in the medical domain that can be solved by agents, we mention: medical diagnostics elaborations, medical information collection from distributed knowledge bases, medical data collection about patients from distributed databases etc.

A *medical diagnosis problem* represents the description of a patient's illness. The solution of the problem represents the identified illness and the proposed diagnostic to cure the illness. Many medical problems that must be solved in the medical domain represent subproblems of medical diagnosis problems. As an example of subproblem, we mention a medical issue whose answer is necessary in a diagnostic establishment. For example, we mention, the issue "if exists a more effective medicine to cure an illness than a medicine known by a physician" (a physician wants to know if exists a more effective medicine to cure an illness than the medicine known by himself).

Many medical diagnosis systems must have specific proprieties, depending on the types of the medical problems that they must solve. One of the main propriety, which many times is required by a diagnosing system, consists in the adaptability realized by learning. By learning medical a medical computational system may increase the detained medical knowledge accuracy. Is not always possible to create a system, which has all the necessary knowledge and the established knowledge has the required accuracy [1, 10, 22]. In the paper [8], an intelligent medical diagnosis systems with built-in functions for knowledge discovery and data mining is described. The implementation of machine learning technology in the medical diagnosis systems seems to be well suited for medical diagnoses in specialized medical domains. By learning, a system can autonomously construct medical diagnosis rules that can be used in diagnosis processes [8].

Difficulties of some medical diagnosis problems, motivate the use of medical multiagent systems for their solving versus medical systems that operate in isolation [52, 14]. Cooperative medical multiagent systems may combine the members capabilities and capacities in the problems solving. A medical diagnostic elaboration may have many difficulties that imply the cooperation of more human and/or artificial medical specialists in their solving [4]. In the following, are mentioned some difficulties in the establishment of a medical diagnostic. A patient may have a combination of illnesses that has different symptoms. The symptoms of more illnesses may have some similarities, which make their identification difficult. Symptoms of an illness can be different at different persons who suffer from that illness. In some situations, a patient does not exhibit the typical symptoms of a specific illness even so he suffers from it. 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 who suffer from that illness. An illness can be in a very advanced stage that makes the diagnostic elaboration difficult. Difficult cases are those in which the patient's symptoms do not sufficiently match typical patterns known by physicians. An illness can be insufficiently known in medicine because it is either new or unusual. In such situations, the symptoms of an illness may or cannot be interpreted properly.

To model agent systems some methodologies were proposed, like: *HIM* [49], *GAIA* [50] and *PASSI* [51]. The paper [6] analyzes different aspects of the multiagent systems specialized in medical diagnosis. Understanding such systems needs a high-level visual view of how the systems operate to achieve some application related purpose. In the paper [6], a novel method of visualizing the behavior of a medical multiagent system called *Use Case Maps* is proposed. There is described a process for designing agent-based systems using a visual technique, that provide a view of the system as a whole.

In the paper [36], a medical diagnosis multiagent system that is organized accordingly to the principles of swarm intelligence is proposed. It consists of a large number of agents that interact with each other by simple indirect communication. The proposed multiagent system real power stem from the fact that a large number of simple agents collaborates with the purpose to elaborate reliable diagnostics. Agents specialized in medical diagnosis can self-organize in order to provide viable medical diagnoses.

The agents represent a very promising recent research direction in medical diagnoses elaborations [11, 12, 14, 36] and fulfilling medical tasks related with the diagnoses processes. The main motivation that confirm the necessity to use agent based applications in medical domains, consists in the possibility to combine different technologies in the same agent body. As examples of applications of the agents for fulfilling medical tasks, we mention: *patients monitoring* [15], *patients management* [16, 17], *healthcare* [18, 19, 54], *telehealth* [52], *spreads simulation of infectious disease* [53], *web-enabled healthcare computing* [54], *ubiquitous healthcare* [19].

3 Related works

3.1 Medical expert system agents

Medical expert systems represent relatively classical applications in the medical diagnosis. As examples of well known medical expert systems, we mention: *MYCIN* [20], *GIDEON* [38], *CARDIAG2* [39], *PUFF* [40] and *CASNET* [41]. Expert systems had some success in specific, mainly quite narrow fields of medical expertise, but had problems to cover broader areas of expertise. Some of the problems related with the expert systems are their limited [37, 2]: flexibility, adaptability, extensibility and cooperation capability. The endowment of the expert systems with cooperation capability is an important research direction [2, 37, 10]. The paper [10] presents a system called *FELINE* composed of five autonomous medical expert systems with some proprieties of the agents. These agents cooperate to identify the causes of anemia at cats. There is also presented a development methodology for cooperating expert systems.

In the paper [52], a Web-centric extension to a previously developed expert system specialized in the glaucoma diagnosis is proposed. The proposed telehealth solution publishes services of the developed *Glaucoma Expert System* on the World Wide Web, allowing physicians and patients to interact with it from their own homes. The *Glaucoma Expert System* uses learning algorithms applied on patient data to update and improve its diagnosis rules.

The *medical expert system agents* represent a novel class of agents developed in our previous works [2, 4, 11, 12, 21, 36]. The medical expert system agents are medical expert systems endowed with agents' capabilities (1).

$$ExpertSystemAgent = ExpertSystem + Agents'Capabilities. \tag{1}$$

A medical expert system agent is endowed with a medical specializations set. As examples of specializations of a medical expert system agent, we mention specializations in subdomains of: cardiology, gastroenterology, endocrinology and rheumatology. Expert system agents can perceive and interact with the environment executing actions in the environment autonomously. Expert system agents can cooperate in the problems solving with other agents and physicians, which allows more flexible problem solving versus the expert systems. If an expert system agent cannot solve a problem (doesn't have the necessary capability and/or capacity), then he can transmit the problem for solving to another agent or physician.

In the papers [12, 48], a cooperative multiagent system specialized in medical diagnosis called *CMDS* (*Contract Net Based Medical Diagnosis System*) is proposed. *CMDS* is a complex system composed from medical expert system agents that cooperatively solve medical diagnosis problems transmitted for solving to the system. For the problems allocation for solving, in the *CMDS* system is used a novel problem allocation protocol, which represents an adaptation of the *contract net problem allocation protocol* [1, 3].

The papers [14, 28] describe a cooperative medical diagnosis system, proposed for difficult medical diagnosis problems solving called *BMDS* (*Blackboard-based Medical Diagnosis System*). *BMDS* is a complex system, composed from: expert system agents and *assistant expert system agents. Assistant expert system agents* represent expert system agents endowed with capability to help intelligently physicians and other agents during the problems solving processes. The assistant agents versus the expert system agents are endowed with knowledge, about the system in which they operate and knowledge about the helped agents and/or physicians. The detained knowledge by them allows the assistance offering. The problems solving by the proposed diagnosis system is partially-based on the *blackboard-based problems solving* [29, 3].

3.2 Medical ICMA agents

The development of *large-scale medical diagnosis systems* represent an important research direction [7, 19, 11]. In the paper [7], an *Internet-based holonic medical diagnosis system* for diseases is proposed. The holonic medical diagnosis system consists of a tree-like structured alliance of agents specialized in medical diagnoses, which collaborate in order to provide viable medical diagnoses, combining the advantages of holonic systems and multiagent systems.

Another important research direction related with the development of large-scale diagnosis systems, is represented by the approaches based on software mobile agents [11, 19]. The *LMDS* system [11] that uses *medical ICMA mobile agents* developed in our previous works and the *OnkoNet* mobile agents [19] described in the literature are illustrative in this sense.

OnkoNet mobile agents have been used successfully for patient-centric medical problems solving [19]. In the paper [19], is introduced the notion *ubiquitous healthcare* (any-time/any-place access of health services via mobile computing), addressing the access of health services by individual consumers using mobile agents. This access requires medical knowledge about the individual health status (relevant recent diseases). The *OnkoNet* mobile agent architecture involve architectures on the macrolevel and microlevel as well as cooperation protocols. The work presented in the paper [19], emerged from a project covering all relevant issues, from empirical process studies in cancer diagnosis/therapy, down to system implementation and validation.

The software mobile agents are capable to change their location in the network where they operate [34, 35]. The main disadvantages of the mobile agents are related with their limited [34, 35]: communication capability, protection capability, intelligence and capability to use knowledge bases in the problems solving. These disadvantages limit the use of the mobile agents for medical problems solving in insecure networks.

In our previous researches a novel mobile agent architecture called *ICMA* (*Intelligent Cooperative Mobile Agent Architecture*) was developed [24, 25]. The proposed mobile agent architecture represents a combination of the mobile and static agent paradigms. The purpose of the research was the development of an architecture that allows the creation of mobile agents, which can solve intelligently difficult problems like medical diagnosis problems in insecure networks. Advantages of the *ICMA* mobile agents versus some of the mobile agents described in the literature consist in their increased: communication capability [25], protection possibility [26] and intelligence [25]. *ICMA* agents can solve efficiently large numbers of problems [24, 25]. These advantages of the *ICMA* agents suggest their use for different problems solving. *ICMAE* (*Intelligent Cooperative Mobile Agents with Evolutionary Problem Solving Capability*) agents represent a novel class of mobile agents developed in our previous works [31, 32, 33]. *ICMAE* agents represent agents with the ICMA architecture endowed with problem solving methods based on evolutionary computation. *ICMAE* agents can solve efficiently large numbers of problems, using efficiently problems solving resources (resources of the hosts) distributed in the network [31, 32, 33].

Medical ICMA agents represent a novel class of medical agents, based on the *ICMA* architecture. *Medical ICMA agents* can diagnoses illnesses. In the paper [11], a large-scale medical diagnosis system called *LMDS* (*Large-Scale Medical Diagnosis System*) is proposed. *LMDS* is a complex system composed from expert system agents and medical *ICMA* agents. The agents' members of the diagnosis system solve cooperatively overtaken diagnosis problems. A medical *ICMA* agent can cooperate with other agents in the problems solving. A medical *ICMA* agent can migrate in the network with an overtaken problem until will find an agent capable to solve the problem. The open *LMDS* system may have a large number of members.

Medical expert system agents represent a novel class of agents with medical diagnosing capability. The effectiveness of the *CMDS*, *BMDS* and *LMDS* multiagent systems demonstrate, that medical expert system agents can be used successfully as members of complex diagnosis systems. The increased intelligence of the expert system agents is proved in [21]. *Assistant medical expert system agents* that are expert system agents endowed with capability to help flexibly physicians in their work, used by the *BMDS* system, proves that expert system agents may help medical specialists during the medical diagnosis processes. Medical expert system agents require future improvements, in order to increase their intelligence in the physicians assistance during the diagnoses processes. Medical expert systems can be useful in situations when are diagnosed illnesses in more diagnosis domains.

4 The MASM multiagent system

In the following, we propose an assistant multiagent system composed from a set $AS = \{As_1, As_2, \ldots, As_n\}$ of *assistant expert system agents* that can help more physicians in they work. We call the proposed multiagent system *MASM* (*Medical Assistant Multiagent System*). In the following, we call the assistant expert system agents shortly *assistant agents*. Physicians own assistant agents' members of the multiagent system. Each physician is the owner of an assistant agent (in the system may exists agents that are not owned by physicians). Figure 1 presents a physician interaction with the proposed multiagent system. The arrows used in Figure 1 present the *types of cooperation* $T = \{t_a, t_c\}$. t_a is a cooperation link between a physician and the owned assistant agent. t_c is a cooperation link between assistant agents.

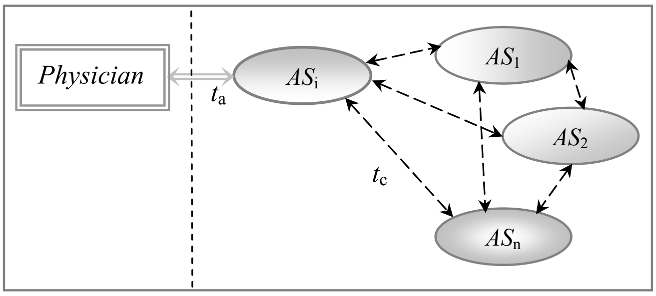

Fig. 1. A physician interaction with the MASM system

A physician denoted Ph_y interacts directly only with its owned assistant agent As_y ($As_y \in AS$, $Link(As_y, Ph_y) = t_a$). As_y can cooperate during its operation with all the other assistant agents' members of *MASM* system with which has a cooperation link by the type t_c (in the system may exists assistant agents between that doesn't exist a cooperation link). Assistant agents can cooperate in different problems solving, like: medical diagnoses elaborations, medical information search, cooperation in the solution finding to emitted medical issues by physicians etc.

4.1 MASM system operation

The algorithm *MASM Problem Solving* describes the cooperative elaboration of a medical diagnostic (a P_k medical diagnosis problem solving) by a physician denoted Ph_e and the agents members of the *MASM* system. As_e ($As_e \in AS$) represents the agent owned by Ph_e ($Link(Ph_e, As_e) = t_a$). The solution $S_k = [Il_z, Tr_v]$ of the P_k problem, represents the patient denoted Pat_c, Il_z illness and the Tr_v treatment that must be applied to cure Il_z.

Algorithm - MASM Problem Solving

{IN: P_k - the diagnosis problem}

{OUT: $S_k = [Il_z, Tr_v]$ - the solution of P_k}

Step 1. Information collection about the patient.

@Pat_c personal informations (name, identification number etc) are collected and transmitted to As_e ($Link(Ph_e, As_e) = t_a$).

@The informations about the patient's illness (the illness symptoms, the history of the symptoms) are collected from Pat_c and transmitted to As_e and Ph_e. The rest of the informations are obtained by physical examination. During the physical examination, Ph_e looks for signs of the illness (signs are manifestations of the illness that the physician can see or feel).

@As_e requires medical informations about Pat_c (Pat_c past illnesses descriptions, Pat_c known allergies to some medicines etc) from an assistant agent As_k ($Link(As_e, As_k) = t_c$). As_e transmits to As_k, the patient Pat_c personal informations, necessary in the Pat_c identification.

@As_k establishes how can obtain the informations required by As_e. In the informations extraction, As_k may requires the help of other assistant agents.

@As_k fulfill the requirement of As_e by transmitting the obtained informations.

@As_e selects from the informations transmitted by As_k, the informations considered useful for Ph_e (informations that describe Pat_c past illnesses and different medical informations about the patient). These informations are transmitted by As_e to Ph_e.

Step 2. The problem cooperative solving.

While (P_k solution is not obtained) *do*

> @Ph_e continues P_k solving. Ph_e may require investigations such laboratory tests, X-rays, MRI, computed tomography etc.
>
> *If* (Ph_e requires the help of As_e) *then*
>
> > @As_e plans how can fulfill the Ph_e requirement cooperatively with assistant agents with that has a cooperation link by type t_c.
> >
> > @As_e tries to realize the Ph_e requirement.
> >
> > *If* (As_e succeeded to realize the Ph_e requirement) *then*
> >
> > > @As_e announces Ph_e about the obtained results.
> > >
> > > *else*
> > >
> > > > @As_e announces Ph_e about its incapability to fulfill the requirement.

EndIf

EndIf

If (As_e establishes the assistance that can offer to Ph_e) *then*

@As_e plans how can help Ph_e.

@As_e helps Ph_e.

EndIf

EndWhile

@Let S_k be the solution obtained by Ph_e.

Step 3. The problem solution formation.

@Ph_e transmits the identified illness and the established treatment to As_e.

If (As_e finds mistakes in S_k) *then*

@As_e announces Ph_e about the mistakes contained in S_k.

If (As_e can suggest measures that can eliminate mistakes) *then*

@As_e suggests to Ph_e the measures that can offer solution to the elimination of the mistakes.

EndIf

@Ph_e eliminates the mistakes from S_k. If is necessary Ph_e cooperates with As_e.

@Let $S_k = [Il_z, Tr_v]$ be the reviewed solution.

EndIf

Step 4. The problem solution validation.

@Ph_e validates S_k. During S_k validation, Ph_e may requires As_e help.

EndProblemSolving.

Figure 2 presents a cooperative diagnosis elaboration by a physician denoted Ph_i and the assistant multiagent system *MASM*, in order to identify a patient's illness and establishes a proper diagnostic to cure the illness. During the diagnostic establishment, Ph_i interacts directly only with the owned assistant agent As_i ($As_i \in AS, Link(As_i, Ph_i) = t_a$).

A problem description (2) contains a list of medical informations and data $St_1, St_2, \ldots, St_m$ that can be obtained during a diagnosis problem solving.

$$< [1 : ty_1 : nr_1 : St_1]; [2 : ty_2 : nr_2 : St_2]; \ldots ; [m : ty_m : nr_m : St_m] > . \quad (2)$$

$St_1, St_2, \ldots, St_m$ from (2) may have a single value or a list of values. As examples of values, we mention: illness symptoms, illness syndromes, illnesses

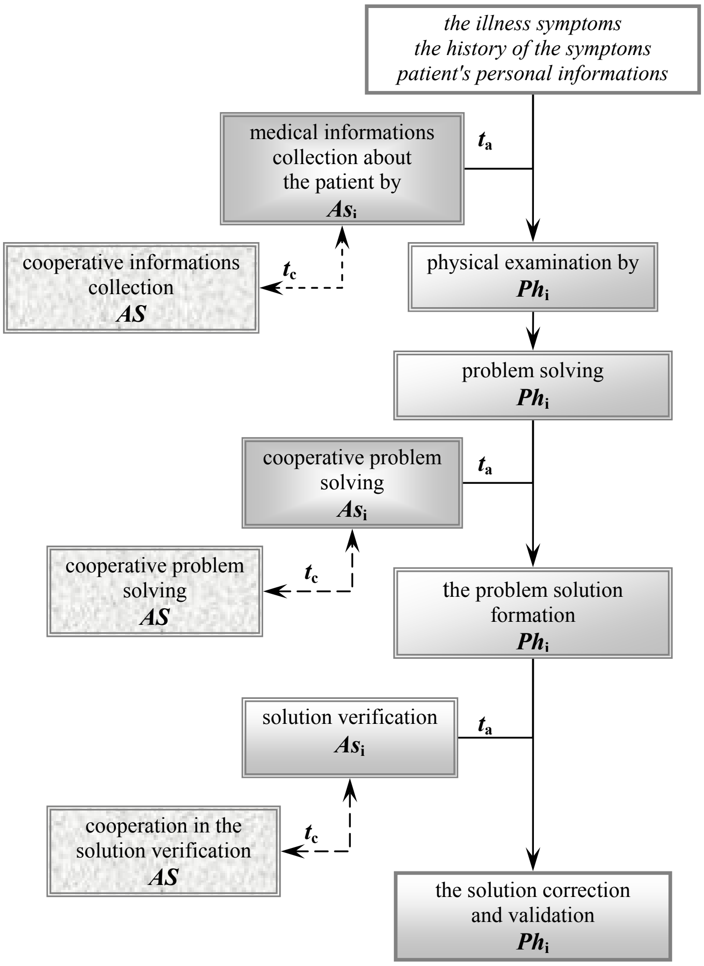

Fig. 2. Summary of a cooperative diagnosis elaboration

from the past, diagnostics etc. To each parameter St_a that can contain effective medical information is associated a numerical value a (a is completed implicitly), a type ty_a of information and/or data that can be retained in the parameter, and a numerical value nr_a that specifies how many values can be retained in St_a.

For example, we mention $[f : ty_f : nr_f : St_f]$ completed during a diagnosis problem solving with $[5 : symptoms : more : list]$; where $f = 5$ (is the parameter on the position 5), $ty_5 = symptoms$ (the parameter contain symptoms), $nr_f = more$ in the list can be retained a list of symptoms. $list$ take values during a problem solving (will be completed with a list of symptoms).

Retaining the medical informations and data about a diagnosis problem denoted P_h in the form (2), allows to the assistant agents to quickly and precisely identify the types the knowledge detained about P_h. The precise identification is necessary in the cooperation between the agents. An assistant agent based on the parameter identifier, knows with which parameter of the preconditions of its diagnosing rules must try to fit in order to establish an applicable rule.

The medical informations and data that can be retained in (2), are established based on the specifics of the illnesses that are diagnosed by the system (for example infectious disease). Initially, a problem description contains informations that describes an illness (for example the illness symptoms enumerated by the patient). During the solving of the problem, the description is changing, by adding new knowledge by physicians or artificial agents. Physicians can add, remove and modify knowledge in a problem description. The physicians can make more rational decisions versus the artificial agents, whose rationality is an automatized one. The final problem description will contains the established diagnostic. During a problem solving, some of the parameter values may not be completed (for example is not necessary to retain the history of the diagnosed illness symptoms).

An AS_b assistant agent knowledge used in medical diagnoses elaborations is composed from a set RL (3) of diagnosing rules.

$$Rl = \{Rl_1, Rl_2, \ldots, Rl_g\}. \tag{3}$$

An Rl_h ($Rl_h \in Rl$) diagnosing rule has the form (4).

$$Rl_h : Prec_h \rightarrow Postc_h. \tag{4}$$

$Prec_h$ and $Postc_h$ have parameters that specify informations, which describe different aspects of a diagnosis process. In $Prec_h$ and $Postc_h$ appear a set Par (5) of parameters (some of the parameters specified in (2)).

$$Par = \{Par_1, Par_2, \ldots, Par_y\}. \tag{5}$$

A Par_p ($Par_p \in Par$) parameter in (5) has the form (6)

$$Par_p = [f : ty_f : nr_f : St_f]. \tag{6}$$

St_f contains medical informations and/or data. $type_f$ represents the type of medical informations retained in St_f. nr_f represents the number (one or more) of values that may have St_f. f is a natural number, which specify the same type of information that specify f in (2). If Par_p appear in the precondition of a rule, then specify conditions tat must be fulfilled for the applicability of the rule in whose precondition appear. If Par_p appear in the postcondition of a rule, then it specify informations that must be added into the problem description (for example a supposed illness or a suggested treatment), which represent the informations about the problem that is diagnosed, if the precondition of the rule is verified. When an agent overtakes a medical diagnosis problem for processing, identify a diagnosing rule which postcondition specify informations that can be added in the problem description. The knowledge contained in a problem description is understandable to the physicians, they can modify it by adding, modifying or retracting knowledge.

An assistant agent As_i ($As_i \in AS$) has a knowledge base that contains different knowledge about the owner physician denoted Ph_i ($Link(Ph_i, As_i) = t_a$) and the agents' members of the *MASM* system. About Ph_i the owned assistant agent As_i may detains informations like:

- Ph_i specialization in medicine;
- Ph_i working program;
- medical informations and data about the Ph_i patients (for example the patients' medical history);
- informations (specialization in medicine, working program) about other physicians that use the system, with who Ph_i usually cooperate in the diagnoses elaborations (require and/or offer advices from/to them).

About an assistant agent As_k ($As_k \in AS$), the assistant agent As_i ($As_i \in AS$, $Link(As_i, As_k) = t_c$) may detains informations like:

- the specializations of As_k (for example information searching capability about physicians);
- the knowledge representation languages used by As_k in the detained knowledge representation. A knowledge representation language allows the representation of the used knowledge [3].

An assistant agent As_h ($As_h \in AS$) can offer autonomously assistance to its owner physician Ph_h ($Link(Ph_h, As_h) = t_a$), based on different knowledge detained in its knowledge base and the informations known about the diagnosis problem that is currently solved by Ph_h. Ph_h may requires explicitly As_h help. In the assistance offering, As_h can cooperate with other agents.

A physician Ph_g can requires its owned As_g ($Link(Ph_g, As_g) = t_a$) agent's help in solving subproblems of a diagnosis problem. As examples of subproblems of a diagnosis problem, we mention:

- the result of a medical analyzes necessary in increasing the accuracy of an illness identification;
- a supposed Il_c illness. Ph_g requires to As_g to analyze if a patient has the Il_c illness. Il_c probability of apparition is estimated to be low by Ph_g.
- the medical ontology known by As_k. A medical ontology represents a dictionary of used terms in a medical domain [42]. As examples of developed medical otologies described in the literature, we mention: *GALEN* [43], *UMLS* [44], *OntHoS* [19], *LinkBase* [45], *TAMBIS* [46] and *GENE* [47].

A physician denoted Ph_g may transmit subproblems to its As_g owned assistant agent, who if is necessary cooperates with a set $As_j, As_v, \ldots, As_q$ of agents in order to solve them (As_g have a cooperation link by the type t_c with $As_j, As_v, \ldots, As_q$). The received results by As_g from $As_j, As_v, \ldots, As_q$ will be transmitted to Ph_g. Ph_g establishes the diagnostic based on its different observations and the results obtained from As_g.

An assistant agent can cooperates with other agents in order to collect medical knowledge and medical informations about patients. As examples of medical informations that can be collected by an agent As_i ($As_i \in AS$) about a patient, we mention the descriptions of the patient's medical history and the patient's current known illnesses. As examples of medical knowledge that can be collected by an agent As_k ($As_k \in AS$), we mention: an illness description (the symptoms of the illness), a new medicine that can be used to cure an illness; the success of different diagnostics applied to cure an illness.

An assistant agent can verify the correctness of a problem's solution obtained by its owner physician. The agent knows the problem that is solved by the physician (the problem description is transmitted to the assistant agent). However, the agent can transmit the problem for solving to another agent that has the necessary medical specialization. For example, a physician specialized in general medicine and an agent specialized in general medicine can try to establish simultaneously a diagnostic to cure an illness. The assistant agent can compare the solution obtained by the physician with the solution obtained by the another agent. If the obtained solutions differ, the assistant agent announces the physician related about the uncertainty of the correctness of the obtained solution.

4.2 Examples of Cooperative Medical Diagnoses Elaborations

An assistant agent can manage intelligently the cooperation between the owner physician and other physicians. In the following, we present two cooperative scenarios. The scenario called *Medical Issue Solving* describes a medical issue cooperative solving by more physicians assisted by the *MASM* system. The scenario called *Medical Diagnosis Problem Solving* describes a medical diagnosis problem solving by more physicians assisted by the *MASM* system. Is considered, that the *MASM* system is used by a set $Ph = \{Ph_1, Ph_2, \ldots, Ph_r\}$ of physicians. $ASR = \{As_1, As_2, \ldots, As_r\}$ ($ASR \subseteq AS$) denote the assistant agents owned by $Ph_1, Ph_2, \ldots, Ph_r$.

The scenario of a medical issue solving

We consider the situation when a physician denoted Ph_i ($Ph_i \in Ph$) wants to find the opinion of more physicians about a medical issue denoted mi. As an example of medical issue that can be emitted by a physician, we mention a hypothesis related with a diagnostic to cure an illness. Cooperation scenario - *Medical Issue Solving* describes the cooperative finding of the answer to the medical issue mi emitted by Ph_i.

Cooperation scenario - Medical Issue Solving

Step 1

$Ph_i(mi) \Rightarrow As_i$.

As_i establishes the physicians $Ph_1, Ph_2, \ldots, Ph_k$ capable to answer to mi.

As_i establishes the agents $As_1, As_2, \ldots, As_k$ owned by $Ph_1, Ph_2, \ldots, Ph_k$.

$As_i(mi) \Rightarrow As_1, As_2, \ldots, As_k$.

Step 2

$As_1(mi) \Rightarrow Ph_1$.

$As_2(mi) \Rightarrow Ph_2$.

$\ldots$

$As_k(mi) \Rightarrow Ph_k$.

Step 3

$Ph_1(rp_1) \Rightarrow As_1$.

$Ph_2(rp_2) \Rightarrow As_2$.

$\ldots$

$Ph_k(rp_k) \Rightarrow As_k$.

Step 4

$As_1(rp_1) \Rightarrow As_i$.

$As_2(rp_2) \Rightarrow As_i$.

$\ldots$

$As_k(rp_k) \Rightarrow As_i$.

Step 5

$learned = ASILearn(rp_1, rp_2, \ldots, rp_k)$.

$useful = Filter(rp_1, rp_2, \ldots, rp_k)$.

$As_i(useful) \Rightarrow Ph_i$.

Ph_i establishes the answer to mi based on the $useful$ knowledge.

EndMedicalIssueSolving

Ph_i transmits mi to its owned agent As_i ($Link(Ph_i, As_i) = t_a$). As_i based on its detained knowledge establishes the physicians $Ph_1, Ph_2, \ldots, Ph_k$ capable (have the necessary medical specialization and are available) to answer to the issue mi. As_i will transmit mi to the assistant agents $As_1, As_2, \ldots, As_k$

owned by the choused physicians $Ph_1, Ph_2, \ldots, Ph_k$ (As_i have a cooperation link by the type t_c with the agents $As_1, As_2, \ldots, As_k$). $As_1, As_2, \ldots, As_k$ will overtake the responsibility to transmit mi to their owner physicians and send back the answer to As_i. $rp_1, rp_2, \ldots, rp_k$ represent the physicians responses to mi. As examples of answers that can be received by As_i from an agent As_j ($Link(As_i, As_j) = t_c$) owned by Ph_j ($Link(Ph_j, As_j) = t_a$), we mention: Ph_j is unavailable, Ph_j answer to the issue, Ph_j cannot answer to the issue. From the received responses, As_i filters the useful responses (contains the physicians responses to the issue). As_i can learn from the received responses. *learned* represents the learned knowledge by As_i. As examples of informations that As_i can learn, we mention: what physicians are usually unavailable, what physicians can answer fast to different issues etc. The knowledge denoted $useful$ obtained after the filtering process is transmitted to Ph_i. Ph_i will establishes the answer to the mi medical issue based on the $useful$ knowledge received from As_i.

The scenario of a medical diagnosis problem solving

We consider the situation when a physician denoted Ph_i cannot solve a medical diagnosis problem denoted P_q. In order to solve the problem, Ph_i cooperates with other physicians. *Cooperation scenario - Medical Diagnosis Problem Solving* describes briefly the cooperative solving of the P_q problem by the physicians helped by the *MASM* system.

Cooperation scenario - Medical Diagnosis Problem Solving

Step 1

$Ph_i(P_q) \Rightarrow As_i$.

As_i establishes the physicians $Ph_1, Ph_2, \ldots, Ph_m$ considered capable to cooperate in P_q solving.

As_i establishes the $As_1, As_2, \ldots, As_m$ agents owned by $Ph_1, Ph_2, \ldots, Ph_m$.

$As_i(P_q) \Rightarrow As_1, As_2, \ldots, As_m$.

Step 2

As_1 verifies if Ph_1 is capable to cooperate in the P_q solving.

As_2 verifies if Ph_2 is capable to cooperate in the P_q solving.

...

As_m verifies if Ph_m is capable to cooperate in the P_q solving.

Step 3

$As_1(rp_1) \Rightarrow As_i$.

$As_2(rp_2) \Rightarrow As_i$.

...

$As_m(rp_m) \Rightarrow As_i$.

Step 4

$PT = TeamFormation(rp_1, rp_2, \ldots, rp_m)$.

P_q is solved cooperatively by the set PT ($PT \subseteq PH$) of physicians interloped by their owned agents.

S_q is formed and validated by the set PT of physicians.

EndMedicalDiagnosisProblemSolving

Ph_i requires the help of the owned assistant agent As_i ($Link(Ph_i, As_i) = t_a$) in finding physicians with who can cooperate in the P_q solving. As_i will establishes the capable physicians $Ph_1, Ph_2, \ldots, Ph_m$ based on the knowledge detained in its knowledge base. $rp_1, rp_2, \ldots, rp_m$ represent the responses (acceptance or rejection) of the physicians $Ph_1, Ph_2, \ldots, Ph_m$ to Ph_i requirement to cooperate in the P_q solving. After that, As_i will manage the cooperation of Ph_i with the set PT ($PT \subseteq PH$) of physicians. PT contains Ph_i and a set of physicians who has accepted the cooperation in the P_k solving. In some of the interactions, the physicians PT can use as interloper their owned agents. P_q solution S_q is formed and validated, cooperatively by physicians from the set of physicians PT, who are specialized in the medical domain (domains) in which the identified illness (illnesses) is included.

Figure 3 presents a diagnosis problem solving complexity distribution between the members of the *MASM* system. In Figure 3 are used the notations: *Problem* presents the problem that is solved; Ph_1, Ph_2,..., Ph_j represent the physicians that contribute to the problem solving; As_1, As_2,..., As_b represent the assistant agents (owned by Ph_1, Ph_2,..., Ph_j, and may contain agents that are not owned by physicians) that contribute to the problem solving.

The scenarios presented before have described cooperative medical problems solving by physicians helped by their owned agents. In the following, we mention different assistance that can offer an agent As_q to its owner physician Ph_q ($Link(Ph_q, As_q) = t_a$) in a P_t medical diagnosis problem cooperative solving by Ph_q with a set $Ph = \{Ph_1, Ph_2, \ldots, Ph_m\}$ of physicians:

- As_q can transmits known information to $Ph_1, Ph_2, \ldots, Ph_m$ without consulting Ph_u. For example, may transmit medical information about the patient whose illness is diagnosed cooperatively by $Ph_1, Ph_2, \ldots, Ph_m$ and Ph_u. However, is not necessary for Ph_u to specify explicitly all the details to $Ph_1, Ph_2, \ldots, Ph_m$ necessary in the P_t solving;
- As_q can add the ontology of the used terms in a message transmitted by Ph_u to another physician Ph_v. For example, may add alternative names of the same illness;

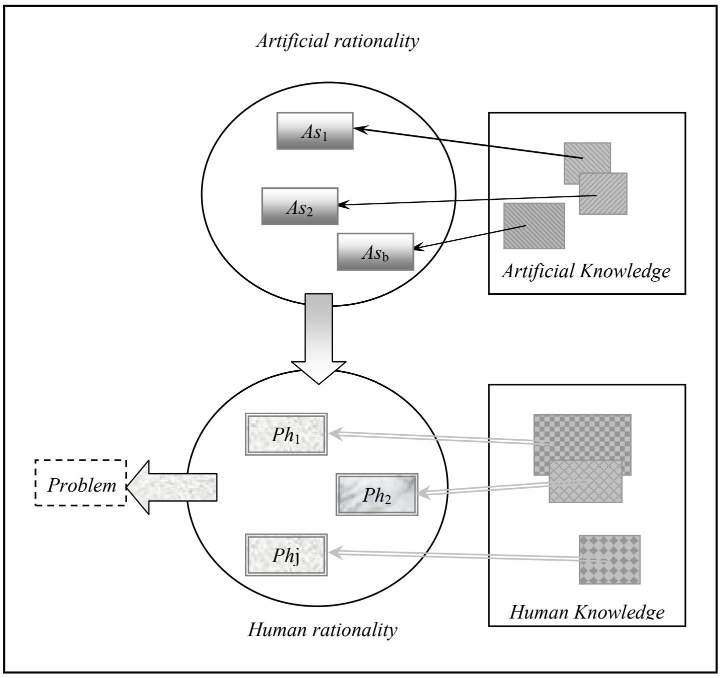

Fig. 3. Problem solving complexity distribution in the MASM system

4.3 Advantages of the MASM System

More physicians can use the proposed *MASM* system. Each physician interacts directly only with an owned assistant expert system agent. Each assistant agent will cooperate during the problems solving, if is necessary with other agents' members of the system. For a physician is necessary to knows only its owned assistant agent, the rest of the system's member agents are hidden to the physician. Each assistant agents know how must cooperate with some other agents to offer the necessary help to its owner physicians. More physicians using as interlopers their owned assistant agents can solve cooperatively medical diagnosis problems.

An external physician (is not in the set of physicians that use the *MASM system*) can use the multiagent system (for example a physician uses the multiagent system just during a problem solving). An assistant agent will manage the interactions of the new physician with the multiagent system and the physicians that already use the system. The external physician's assistant agent is endowed with an initial set of knowledge about the physician. During its life cycle, the assistant agent can learn new knowledge that improves its capability to help the physician in the future.

The *MASM* system cannot substitute the physicians, but the cooperation with the physicians may improve the elaborated diagnostics accuracy by the physicians. A final diagnostic establishment and validation in the case of an illness is the responsibility of a physician. By cooperation, the human and artificial thinking advantages in the diagnostics elaboration are combined. Physicians can elaborate decisions using their medical knowledge and intuition formed in time. However, they can diagnoses difficult illnesses. The diagnostics accuracy and elaboration time can be improved, if in some points of decisions, the physicians use the *MASM* system that can verify medical hypotheses and execute different actions autonomously, in order to make the physicians work easier.

An assistant agent's specialization contains the description of the help that can offer the agent to physicians and other agents. An assistant agent can be endowed with new specializations; the inefficient specializations can be eliminated or improved. New assistant agents can be introduced in the multiagent system. 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 [1, 2, 3].

5 Conclusions

The solving of many medical diagnosis problems is a complex task that may require diagnosing knowledge from different medical domains, which cannot be detained by a single physician or a single medical computational system. Recently developed medical agents and medical multiagent systems, prove that they represents an efficient approach for many diagnosis problems solving [27, 24, 23, 28, 11, 12, 14, 36]. Agents may fulfill medical tasks, related with the diagnostics elaborations and treatments fulfilling. As examples of applications of the agents for fulfilling medical tasks, different than medical diagnoses, we mention: patients monitoring and management [15, 16, 17], healthcare related problems solving [18, 19, 54, 12] and telehealth [52].

In this paper, we have proposed a novel assistant multiagent system called *MASM* (*Medical Assistant Multiagent System*) that can help more physicians during the medical diagnosis problems solving. *MASM* system partially handle the complexity of the diagnosis problems solving, by realizing tasks that may increase the diagnostics accuracy and makes easier the medical diagnoses elaborations by physicians.

The proposed medical diagnosis system is a complex system. It is composed from assistant expert system agents, which cooperate in order to discover difficult medical diagnosis problems solutions. Difficult medical cases are those in which is difficult the illnesses identification and the corresponding efficient treatments establishment. *Medical expert system agents* represent a novel class of agents developed in our previous researches. Applications of the medical expert system agents presented in [12, 48, 11], demonstrate that they can be used as members of complex medical multiagent systems. *Assistant expert system agents* represents a novel class of agents developed in our previous works [14, 28]. *Assistant expert system agents* represent an adaptation of the medical expert system agents, in order to help flexibly physicians and other agents in the problems solving. The main novelty in the *MASM* complex system consists in the intelligent assistance of the physicians. The intelligence of a system can be measured how "well" (flexibility, accuracy, efficiency, capability to handle uncertainties) the system can solve complex problems.

One of the purposes of the development of complex systems consist in the efficient solving of difficult problems. The developed assistant *MASM* multiagent system is illustrative in this sense. Represents a solution for helping physicians in difficult problems solving by decreasing the complexity of the medical tasks that the physicians must fulfill. The system's members cooperate in order to handle the complexity of the problems solving. They can discover cooperatively emergent properties that arise during the medical problem solving processes, which improve the system's future operation.

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