AGENT-BASED MEDICAL DIAGNOSIS SYSTEMS

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Manuscript received 7 December 2006; revised 21 May 2007
Communicated by Patrick Brézillon and Jozef Kelemen

Abstract. Medical diagnostics elaboration many times is a distributed and cooperative work, which involves more medical human specialists and different medical systems. Recent results described in the literature prove that medical diagnosis problems can be solved efficiently by large-scale medical multiagent systems. Cooperative diagnosing of medical diagnosis problems by large-scale multiagent systems makes the diagnoses elaborations easier and may increase the accuracy of elaborated diagnostics. The purpose of the study described in this paper consists in the development of a novel large-scale hybrid medical diagnosis system called LMDS. The LMDS system is composed from physicians, medical expert system agents developed in our previous works and medical ICMA agents. Medical ICMA agents represent a novel class of agents with the ICMA architecture developed in our previous works, endowed with medical diagnosis capability. The main novelty of the LMDS system consists in the novel classes of agent members of the system and the manner in which the members of the system contribute to the problems solving. Each diagnostics can be elaborated cooperatively by more members of the system. The diagnosis system can solve difficult medical diagnosis problems whose solving must be discovered cooperatively by the members of the system. Many difficult medical problem solving requires medical knowledge that cannot be detained by a single physician or a medical computational system. Simulations prove the correctness in operation of the LMDS system.

Keywords: Medical diagnosis, medical diagnosis systems, complex systems, intelligent agents, multiagent systems, cooperative problem solving, medical applications, computational methods in medicine, applications to biology and medical sciences, medical expert system agents
1 INTRODUCTION

The agents represent cognitive systems with proprieties, like [2, 8]: increased autonomy in operation, communication and cooperation capability with other systems and learning capability. In the following, agents are humans and the artificial systems with agents’ proprieties. An agent has [2, 8, 24] a problem solving capability and capacity. The capability of an agent consists in the specializations that the agent can use in the problems solving. A problem solving specialization represents a problem solving method. The capacity of an agent defines the resources that the agent can use in problem solving. The systems composed from more agents are called multiagent systems [25, 8, 41]. Many difficult problems solving is a naturally cooperative process, whose solving implies a cooperative multiagent system. Motivations of the use of cooperative multiagent systems in problem solving consists in the limited capabilities and capacities of individual agents.

Important applications of the agents and multiagent systems are in different problem solvings that appear in medicine [42, 43, 44, 36, 45, 54, 55, 58, 36, 62]. Many researches in the use of the agents in medicine represent the recent research direction, which intends to eliminate disadvantages of earlier developed medical computational systems (medical expert systems for example), that usually consist in limited autonomy, interaction capability with the environment and intelligence in the problem solving. As examples of medical problems that can be solved by artificial agents, medical diagnostics elaboration, medical data collections about patients, medical knowledge search, medical decisions support, pro-active assistance of the physicians during cooperative problem solving (for example, cooperative finding of the answer to the medical issue “the effectiveness of the latest treatment to cure an illness in a very advanced stage” by more physicians helped in their cooperation by their assistant agents) etc. can be mentioned. Medical diagnostics elaborations are often naturally distributed and cooperative processes, which involve human medical specialists and different medical systems [2, 14, 23, 36, 45]. Many medical diagnosis problems can be solved efficiently by large-scale medical multiagent systems [7, 9, 13]. In this paper, a novel hybrid large-scale medical diagnosis system that combines the advantages of humans and agents in medical diagnostics elaborations is proposed.

The paper is structured as follows.

In Section 2, agent-based applications used for medical problems solving are presented. Medical problems are described, for whose solving agent-based approaches and large-scale medical diagnosis systems are used. A novel class of agents called medical expert system agents is presented, developed in our previous works, used as a member in the novel BMDS (Blackboard-Based Medical Diagnosis System) and CMDS (Contract Net-Based Medical Diagnosis System) medical diagnosis systems.

In Section 3, a novel medical diagnosis system called LMDS (Large-Scale Medical Diagnosis System) is proposed. A novel class of medical agents members of the developed system is presented, called medical ICMA agents. Previous works related
with the medical ICMA agents are described; advantages of the LMDS system and the motivations of the system’s development are presented.

In Section 4, the conclusions related with the proposed LMDS diagnosis system and the following research that will be made are presented.

2 AGENT-BASED MEDICAL PROBLEMS SOLVING

Agents have been applied for many problem solving that appear in the medical domains. As examples of applications of the agents and multiagent systems in medicine, we mention: patients monitoring [42], patients management [43, 44], healthcare [36, 45], telehealth [54], healthcare emergency coordination and decision-support [55], web-enabled healthcare computing [58], ubiquitous healthcare [36] and simulation of spreads of infectious diseases [62]. The paper [14] describes the state of the art of medical information systems and technologies at the beginning of the 21st century. The complexity of construction of full-scaled clinical diagnoses is also analyzed.

A medical diagnosis problem consists in the description of an illness (combination of illnesses). The solution of a medical diagnosis problem represents the identified illness (illnesses) and the treatment (treatments) that must be applied to cure the illness (illnesses). The establishment of a medical diagnostic may have different difficulties [14, 51, 52, 53]. A patient may have combinations of illnesses; each of them may have different symptoms and syndromes, there may be dependencies between the patient’s illnesses treatments (for example, a very effective medicine to cure an illness has negative effects to cure the other illness). The symptoms of more illnesses may have some similarities, which make their identification difficult. The symptoms of an illness can be different with different persons who suffer from that illness. In some situations, a patient does not exhibit the typical symptoms of a specific illness even if s/he suffers from it. In the case of some illnesses, the causes of the illnesses are not sufficiently known. A medicine to an illness may have different effects at different persons who suffer from that illness. A person may have allergy to a medicine (this information can be known in the person’s medical history).

An illness can be in a very advanced stage, that makes the diagnostic elaboration difficult (a usual treatment known to be effective to cure the illness in a less advanced stage cannot be applied). For example, we mention a huge tumor whose treatment requires more surgery interventions that must be realized in time. The treatment of such an illness must be carefully planned analyzing different situations (the loss of a huge quantity of blood during a surgery intervention) that can appear during the treatment application. Difficult medical cases are those, in which the patients’ illnesses does 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.

In the medical domains many medical diagnosis systems are used that operate in isolation or cooperate [14, 1, 13, 12, 15, 5, 6, 9, 10, 3, 23, 47]. One of the most
recent research direction is represented by the *agent-based medical diagnosis* [5, 3, 13, 26]. Many difficult medical diagnosis problems must be solved cooperatively by more agents, members of a multiagent system, endowed with different medical knowledge [5, 3, 9, 10]. Some of the recently developed medical multiagent systems act as assistant of the physicians during medical problem solving. A motivation of cooperative solving of difficult medical diagnosis problems by multiagent systems consists in the limited knowledge and resources of the individual agents. Some diagnosis problems must be solved before a deadline. A subclass of the medical multiagent systems is represented by the *medical hybrid multiagent systems* [3, 5, 23]. A medical hybrid multiagent system is composed from different types of software agents and/or of robotic agents and/or human specialists.

Expert systems represent relatively classical applications that can solve problems like human specialists [50]. Expert systems can be endowed with medical diagnosis capability [12, 29, 32]. As examples of well known medical expert systems, we mention: *MYCIN* [28], *GIDEON* [29], *CARDIAG2* [30], *PUFF* [31] and *CASNET* [32]. In the paper [12], a general methodology based on Computer Algebra for constructing rule-based medical expert systems is proposed. For the implementation of the medical expert systems, the paper [12] proposes the *CoCoA language*.

Expert systems had 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: flexibility, adaptability, extensibility and cooperation capability [33, 8]. The endowment of the expert systems with cooperation capability represents an important research direction [8, 33, 15]. In the paper [15], a system called *FELINE* composed of five autonomous agents (expert systems with some proprieties of the agents) endowed with medical knowledge is presented. These agents cooperate to identify the causes of anemia at cats. The paper [15] also presents a tentative development methodology for cooperating expert systems.

The *medical expert system agents* developed in our previous works represent expert systems specialized in medical diagnosis endowed with agents’ capabilities [5, 6, 8, 10]. The medical expert system agents can perceive and interact with the environment. They can learn and execute different actions in the environment autonomously. They can communicate with other agents and humans that allow cooperative problem solving. A medical expert system agent can be endowed with specializations in more medical domains, for example with specializations in gastroenterology, endocrinology and rheumatology. Expert system agents can solve more flexibly and precisely a larger variety of problems than the expert systems [5, 8, 10]. The expert system agents increased intelligence versus the expert systems’ intelligence is analyzed in [16]. Expert system agents can help physicians intelligently in different medical decisions elaboration [24].

In the papers [10, 3, 23], we have proposed a cooperative hybrid medical diagnosis system called *BMDS* (*Blackboard-Based Medical Diagnosis System*). The BMDS is composed from: physicians, *medical expert system agents* and different classes of assistant agents. The cooperative medical diagnosis problems solving by the diag-
Agent-Based Medical Diagnosis Systems

The diagnosis system is partially based on the blackboard-based problem solving \cite{2, 46}. The problem solving by the BMDS system is similar with some cases in which more physicians with different medical specializations plan a difficult diagnostic establishment. The diagnosis system is proposed for difficult medical diagnosis problems solving (patients that suffer from combinations of illnesses) \cite{3}. More agents may contribute to an overtaken medical diagnosis problem in the system, depending on the problem solving specializations. Each agent member of the system is specialized in different aspects of the medical problems solving.

In the papers \cite{6, 5}, we have proposed a cooperative hybrid medical diagnosis system called CMDS (Contract Net Based Medical Diagnosis System) that can solve a large variety of diagnosis problems. The CMDS system is composed from physicians and medical expert system agents. The problem solving specializations in the system are distributed between the agents’ members. CMDS is an open system that can accept new agents as members. For the allocation of problems for solving, in the CMDS system a novel problem allocation protocol is used \cite{11}, which represents an adaptation of the contract net problem allocation protocol \cite{25, 2, 63, 64}. The diagnosis system can solve randomly transmitted problems for solving to the agents. Agents may help each other during the problem solving processes by transmitting different useful medical information \cite{5}. Medical information received during a diagnosis process may help an agent in the decisions elaboration, as well as in precise establishment of a problem solving and in the establishment of the best-fitted agent capable to solve a problem.

In the paper \cite{26}, a self-organizing medical diagnosis system, mirroring swarm intelligence to structure knowledge in holonic patterns is presented. The system sets up on an alliance of agents specialized in medical diagnosis that self-organize in holoarchy in order to provide viable medical diagnoses. Despite the difficulty of the problems that can be solved, the proposed agents exhibit a simple architecture built on reactive behavior. The main advantage of the diagnosis system consists in the fact that relatively simple agents can elaborate reliable diagnosis.

As more health-care providers invest on computerized medical records, more clinical data is made accessible. Diagnosis systems with built-in functions for knowledge discovery and data mining, concerning extracting and abstracting useful rules from such huge repositories of data, are becoming increasingly important for purposes such as of offering better service or care. In the paper \cite{27}, an intelligent medical diagnosis system with built-in functions for knowledge discovery and data mining is described. The implementation of machine learning technology in medical diagnosis systems seems to be well suited for medical diagnoses in specialized medical domains. Automatically generated diagnosis rules may be used in diagnostics elaborations.

In the paper \cite{13}, an Internet-based holonic medical diagnosis system for diseases is proposed. The proposed medical multiagent system combines the advantages of holonic systems and multiagent systems in order to implement an efficient and robust Internet-based diagnosis system for diseases. The proposed system consists of a tree-like structured cooperative alliance of agents specialized in medical diag-
noses. Agents at higher levels of the holarchy are specialized in a broader field of
diseases, while the leaves are experts in one specific disease. Higher level agents
gather the results from all those immediate lower-level agents to which they had
assigned a diagnosis request. They evaluate these results in order to come to a more
comprehensive conclusion. If the results of such an analysis are not satisfying, the
agents may decide to announce the request for a diagnosis to other agents spread
over the Internet that may be able to contribute to the diagnosis generation.

Independent LifeStyle Assistant (ILSA) [56, 57] implemented by Honeywell Lab-
oratories is an agent-based monitoring and supporting system to help elderly peo-
ple to live more independently at home, by reducing caregivers load. It consists
of a multi-agent system supporting continuous data monitoring via home-installed
sensors. The collected data are processed to obtain response planning and machine
learning. ILSA is implemented using the JADE agent platform.

3 LMDS DIAGNOSIS SYSTEM

3.1 Medical ICMA Agents

An agent architecture is essentially a map of the internals of an agent, its data
structures, the operations that may be performed on these data structures, and the
control flow between these data structures [25].

The software mobile agents can be considered a relatively new paradigm in the
area of distributed programming and a useful supplement of traditional techniques
like the Client/Server architecture. Mobile agent technology has been applied to
develop the solutions for various kinds of parallel and distributed computing prob-
lems [48]. Many of the formal modeling of mobile agents is in terms of their mobility,
they are not built upon a framework that explicitly supports the intelligent feature
of the agents [48, 17, 18]. Many times, the multiagent systems formed by coopera-
tive mobile agents are considered to be intelligent. The mobile agents’ intelligence
is considered at the level of multiagent system in which they operate. If the mo-
bile agents cooperate they can solve difficult problems intelligently [48, 36]. Other
disadvantages of recently developed mobile agents are in limitations related with
the [49, 17, 18]: communication capability and protection possibility against dif-
ferent network sources and malicious hosts. The disadvantages mentioned before
result from the mobile agents proprieties such as: mobility (the mobile agents mi-
grate in the network during their operation), autonomy in migration, distributed
and asynchronous operating manner.

In the papers [7, 4], we have proposed a novel mobile agent architecture called
ICMA (Intelligent Cooperative Mobile Agent Architecture). Mobile agents endowed
with the ICMA architecture are called ICMA agents. An ICMA agent denoted
MA is composed from two parts (1): a static part denoted $S_s$ and a mobile part
denoted $M_p$.

$$MA = \langle S_s; M_p = \{M_1, M_2, \ldots\}\rangle$$  (1)
A subagent of an agent represents a component of the agent that has agent’s proprieties [8, 2]. An agent may have more subagents. Ss is the static subagent of MA (Ss doesn’t migrate in the network during its life cycle). The static subagent is responsible for the overtaking of the problems for solving. \( Mp = \{M_1, M_2, \ldots\} \) contains a variable number of mobile subagents. Ss creates the mobile subagents. During its life cycle Ss can create new mobile subagents and eliminate the inefficient or useless mobile subagents. The mobile subagents have all the proprieties of the mobile agents described in the literature, they are responsible for the problems solving at the hosts distributed in the network [7, 4]. The hosts execute the problems solving descriptions from the mobile subagents’ body. The papers [7, 4] analyze the ICMA agents’ knowledge bases and operation.

ICMA agents can communicate efficiently [4]. The communication between different ICMA agents is realized via the subagents of the agents. Mobile subagents at different hosts can communicate using as interloper their creator static subagents (the static subagents addresses are not changing during their live cycle). A mobile subagent may transmit a message to a target mobile subagent, even if the target mobile subagent migrates in the network in the transmission time.

The ICMA architecture offers new security solutions in the protection of the mobile agents against the network sources and malicious hosts [19]. The increased security solutions are offered by the specific distributed operating manner of the ICMA agents (a network source or a host cannot access and/or modify all the information contained in the mobile part of an ICMA agent). During its life cycle, a created mobile subagent leaves the unnecessary knowledge (the mobile part of an ICMA agent deceases in size during a problem solving cycle). During a mobile subagent operation the static subagent can check the mobile subagent status, which hosts specified in the mobile subagent itinerary are not visited and which information contained in the mobile subagent body is modified without authorization.

An ICMA agent can solve problems intelligently [7]. The static subagent represents the intelligent part of an ICMA agent. A static subagent can be endowed with capabilities of the intelligent static agents, and can use resources of the computational system on which it operates. The limitations in the endowment of the mobile agents described in the literature consists in the limited resources and capabilities that they can use in the network and at the hosts. The endowment of a mobile agent with intelligence (for example, a component capable of autonomous learning) increases the agent’s behavioral complexity and the body size. A large number of intelligent mobile agents transmitted in the network may overload the network with data transmission. A large number of intelligent mobile agents at a host may overload the host with data processing. ICMA agents can form intelligent cooperative multiagent systems [4]. The motivation consists in the capability of the ICMA agents to use efficiently the knowledge and resources detained by the static subagents for the efficient use of resources at the hosts.

A novel class of agents developed in our previous work is represented by the ICMAE agents (Intelligent Cooperative Mobile Agents with Evolutionary Problem Solving Capability) [20, 21, 22]. ICMAE agents are agents with the ICMA archi-
tecture, endowed with problem solving specializations based on genetic algorithms. The ICMAE agents operation is the same as ICMA agents operation, the only difference is in the specializations used at the hosts. In the case of the ICMAE agents, the hosts execute problem solving specializations based on genetic algorithms. During its life cycle an ICMAE agent can use the resources of its static subagent and resources of the hosts. The developed ICMAE agents prove that the novel ICMA architecture allows the creation of agents that can solve efficiently problems using genetic problem solving methods.

Simulations has been proposed as an efficient method for analyzing the complex nature and dynamic aspects of the mobile agents [59, 60, 61]. Simulations allow mobile agents to be analyzed and tested in a controllable environment before an actual implementation is built. The difference between simulation and the real implementation is that, in the simulation approach, the execution of a mobile agent is under the control of a simulator which can embody most major characteristics of the real operating environment such as the underlying network. Simulations of an ICMA [4, 7] and an ICMAE [21, 22] agent have been made. The simulated mobile agents have solved problems in problems solving cycles. A problem solving cycle begins, when a set of problems is overtaken for solving and is finished when all the overtaken problems are solved. The simulations were made for different sets of overtaken problems, with the purpose to analyze how the number of mobile subagents created by a static subagent influences the performance (the time when all the overtaken problems are solved) of large numbers of problems. For each sets of problems and each number of created mobile subagents, simulations have been made for different overloading degrees of the hosts. In practical applications, more mobile agents may operate simultaneously at the same host that may overload the hosts from the environment in different degrees.

Simulations of the ICMA agent were realized in an environment composed from 10 hosts, transmitting between 40 and 80 problems to the agent for solving at each problem solving cycle. The ICMA agents were endowed with different sets of problem solving specializations (require different problem solving time). The static subagent has created between 1 and 11 mobile subagents at each problem solving cycle. Table 1 presents the improvement of the problem solving time of the simulated ICMA agent, in the solving of 50 or 80 problems, using a single mobile subagent versus the use of 2 to 11 mobile subagents. The first column in Table 1 shows the number of created mobile subagents, with which a single mobile subagent performance is compared in the solving of the same problems. The second and third columns present the improvement in the problem solving (how many times the use of more mobile subagents improves the problem solving time) in the case of a set of 50 and 80 problems averaged, realizing 50 simulations for different overloading degrees of the hosts.

Simulations of the ICMAE agent were realized for problems sets composed between 30 and 65 problems, using between 1 and 10 mobile subagents, in an environment composed from 3 hosts. The ICMAE agent was endowed with problem solving specializations based on genetic algorithms. Table 2 presents simulation results of
the ICMAE agent. The first column in Table 2 presents the number of created mobile subagents. The second, third and fourth columns show the average problem solving time (when the created mobile subagents have solved all the overtaken problems) in the solving of 30, 50 and 65 problems, realizing 50 simulations for different overloading degrees of the hosts.

<table>
<thead>
<tr>
<th>Subagents</th>
<th>30 problems</th>
<th>50 problems</th>
<th>65 problems</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. 1</td>
<td>462 msec</td>
<td>558 msec</td>
<td>601 msec</td>
</tr>
<tr>
<td>No. 2</td>
<td>282 msec</td>
<td>372 msec</td>
<td>403 msec</td>
</tr>
<tr>
<td>No. 3</td>
<td>186 msec</td>
<td>258 msec</td>
<td>306 msec</td>
</tr>
<tr>
<td>No. 4</td>
<td>138 msec</td>
<td>198 msec</td>
<td>224 msec</td>
</tr>
<tr>
<td>No. 5</td>
<td>102 msec</td>
<td>150 msec</td>
<td>175 msec</td>
</tr>
<tr>
<td>No. 6</td>
<td>84 msec</td>
<td>138 msec</td>
<td>152 msec</td>
</tr>
<tr>
<td>No. 7</td>
<td>74 msec</td>
<td>115 msec</td>
<td>138 msec</td>
</tr>
<tr>
<td>No. 8</td>
<td>66 msec</td>
<td>104 msec</td>
<td>109 msec</td>
</tr>
<tr>
<td>No. 9</td>
<td>54 msec</td>
<td>95 msec</td>
<td>104 msec</td>
</tr>
<tr>
<td>No. 10</td>
<td>43 msec</td>
<td>72 msec</td>
<td>84 msec</td>
</tr>
</tbody>
</table>

Table 2. Simulation results of an ICMAE agent

The simulation results of the ICMA and ICMAE agents prove that the performance of a proposed mobile agent (ICMA and ICMAE) that uses more mobile subagents outperforms the performance when a single mobile subagent is used to solve the same set of problems composed from a large number of problems (sets consisting of between 40 and 80 problems in the case of the ICMA agent and sets consisting of between 30 and 65 problems in the case of the ICMAE agent).

OnkoNet mobile agents, described in the literature, have been used successfully for patient-centric medical problem solving [36]. The paper [36] introduces the notion ubiquitous healthcare (any-time/any-place access of health services via mobile computing devices), addressing the access of health services by individual consumers applying to mobile computing devices. This access requires different medical know-
ledge about the individual health status (relevant recent diseases or already available diagnostics). The OnkoNet mobile agent architecture involves architectures on the macrolevel and microlevel as well as cooperation protocols, and inference models for controlling the system’s behavior. A developed medical ontology called OntHoS is presented, which consists in a collection of terms and definitions to represent organizational structures and processes in hospitals. The work presented in [36] emerged from a project covering all relevant issues from empirical process studies in cancer diagnosis/therapy down to system implementation and validation.

Mobile agents with the ICMA architecture can be endowed with medical diagnosing knowledge. This novel class of medical agents is called medical ICMA agents. Some introductory elements about the medical ICMA agents are presented in [9]. The medical ICMA agents represent a class of agents similar with the OnkoNet mobile agents, capable to solve medical problems. A proposed medical ICMA agent, denoted $MA$ has a set $Spec(\text{MA}) = \{S_1, S_2, \ldots, S_m\}$ of medical specializations obtained by its static subagent denoted $Ss$. As examples of medical specializations with which $MA$ can be endowed, we mention diagnosing knowledge in: general medicine, dermatology, oncology and cardiology. Fig. 1 presents a medical ICMA agent denoted $MA$ which uses the $M_1, M_2, \ldots, M_n$ mobile subagents launched for problems solving in the network. $P_1, P_2, \ldots, P_v$ represent the medical problems transmitted for solving to $MA$. The problems are overtaken by the static subagent $Ss$ of the agent $MA$.

The ICMA agents operation is described in [7, 4]. An ICMA agent can be specialized in problems allocation for solving to other agents that operate in the same environment, using mobile subagents created by the static subagent of the agent [4]. The medical ICMA agents operation (problem solving) and problem allocation for solving is the same as the ICMA agents operation, the only difference consists in the specializations used by the static subagent (the static subagent of a medical ICMA agent is endowed with specializations in medical diagnosis).
If the static subagent $S_s$, of a medical ICMA agent $MA$, cannot solve an overtaken problem (does not have the necessary capability and/or capacity), then the problem must be allocated for solving to another agent with medical knowledge. The problem can be allocated for solving by a mobile subagent of $MA$ created by $S_s$. A mobile subagent may migrate in the network with an overtaken problem until the problem is solved. During its migration more agents may contribute to the problem solving, each of them making modifications on the statement of the problem solving. Each modification has as purpose to enclose the statement of the problem solving to the solution of the problem (the diagnosis that must be established). $SS$ life cycle is the same with $MA$ life cycle. A mobile subagent’s life cycle is beginning, when the mobile subagent is launched for a problem solving, and is finished when the mobile subagent has returned the overtaken problem solution to its creator – static subagent. During its life cycle, $SS$ creates different sets of mobile subagents that are launched for problems solving.

3.2 The LMDS Diagnosis System Description

In this paper, a cooperative hybrid medical diagnosis multiagent system called LMDS (Large-Scale Medical Diagnosis System) is proposed. Some introductory elements about the proposed diagnosis system are described in [9]. The LMDS system denoted $MDS$ is composed from (2): a set $MD$ of agents and a set $H$ of hosts.

\[
MDS = MD \cup H,
\]

\[
MD = D_1 \cup D_2 \cup \ldots \cup D_i,
\]

\[
H = \{H_1, H_2, \ldots, H_i\},
\]

\[
\forall j = 1, i, H_j \prec (D_j = \{D_{j1}, D_{j2}, \ldots, D_{jq}\}). \quad (2)
\]

Each host $H_j$ has a set $D_j = \{D_{j1}, D_{j2}, \ldots, D_{jq}\}$ of submitted agents: physicians, *medical expert system agents* and *medical ICMA agents*. Due to the cooperative solving of the medical problems by physicians and artificial agents the physicians are called “agents” (to a problem solving may contribute both artificial agents and humans). The medical ICMA agents have been described in the previous section. The medical expert system agents have been developed in our previous works. The CMDS [6, 5] and BMDS [10, 3, 23] medical multiagent systems, presented in the previous section, use medical expert system agents as members. Figure 2 presents the proposed LMDS system. $Mob_k, Mob_{k1}, \ldots, Mob_k$ represent sets of ICMA mobile subagents, created by medical ICMA agents, launched to the hosts $H_1, H_2, \ldots, H_i$ for problem allocation for processing.

The environment in which the LMDS system operates is a heterogenous one. The artificial agents and the hosts operate in a network. The physicians operate in physical medical environments. The agents from the set $MD$ can diagnose illnesses corresponding to their capability. The capability of an agent specialized in medicine consists in the medical specializations detained by the agent.
For example, a physician specialized in cardiology can diagnose cardiology related illnesses. An expert system agent may have specializations in more medical domains.

The hosts represent artificial computational systems distributed in the network with capability to accept ICMA mobile subagents [4, 7]. Each host detains information about some of the agents’ members of the diagnosis system. We call the agents about which a host detains information “submitted agents” to the host. Each agent is submitted to a single host. As examples of information detained by a host $H_u (H_u \in H)$ about a submitted agent $Ag_c (Ag_c \in MD)$, we mention: the specializations of $Ag_c$, the resources detained by $Ag_c$ that can be used in the problem solving, etc. Each host detains different information about the other hosts from the diagnosis system. A host $H_u (H_u \in H)$ may have e.g. the following information about another host $H_v (H_v \in H)$: the number of agents submitted to $H_v$, the capabilities and capacities of the agents submitted to $H_v$, the type (human or artificial) of each agent submitted to $H_v$ etc. Each host can communicate and cooperate with the submitted agents (human and artificial).

A host may assist the submitted physicians during problem solving processes. As examples of assistance that can be offered by a host $H_r (H_r \in H)$ to a submitted physician denoted $PH_k (PH_k \in MD)$, we mention:
• $H_r$ translates the knowledge transmitted by a mobile subagent into an understandable form to $PH_k$. For example, $H_r$ may translate an illness symptoms descriptions from English into Italian;

• $H_r$ memorizes medical information transmitted to $PH_k$ until $PH_k$ will have time to overtake the information. $PH_k$ receives the transmitted information when available;

• $H_r$ searches for medical knowledge required by $PH_k$ in distributed knowledge bases. For example, $PH_k$ may require from $H_r$ the description of an illness;

• $H_r$ searches for medical data about a patient in distributed medical databases. For example, $PH_k$ may require the patient’s previous illnesses descriptions.

Figure 3 presents a physician denoted $PH_k$ ($PH_k \in MD$) interaction with the MDS system. In Figure 3 the following notations are used: $H_i$ represents the host with which $PH_k$ interacts during its operation ($PH_k$ is submitted to $H_i$); $H_j$, $H_r$, . . . , $H_s$ represent the host about which $H_i$ detains different information (submitted agents to the hosts, submitted agents specializations etc.); $Ag_z$, $Ag_x$, . . . , $Ag_c$ represent the agents (human and artificial) submitted to $H_i$; $M_f$, $M_g$, . . . , $M_h$ represents ICMA mobile subagents arrived for problems allocation for processing at the host $H_i$.

Fig. 3. A physician interaction with the LMDS system
In the following, operation of the LMDS system is described. The problems are transmitted randomly to the medical ICMA agents’ members of the system. Each medical ICMA agent can receive problems transmitted for solving. A problem solving cycle is beginning, when the problem is received for solving, and is finished when the problem solution is obtained. The Algorithm - Cooperative Medical Problem Solving describes a diagnosis problem \( P_k \) solving cycle by the MDS system. The static subagent denoted \( S_s \) of a medical ICMA agent denoted \( MA \) overtakes the problem \( P_k \) description.

**Algorithm – Cooperative Medical Problem Solving**

{IN: \( P_k \) – the medical problem}

{OUT: \( SOL_k \) – the solution of \( P_k \)}

**Step 1**

@\( S_s \) overtakes the information that describes the problem \( P_k \).

**Step 2**

\( If (S_s \text{ has the capability and capacity to processes the problem } P_k) \text{ then} \)

\( @S_s \) processes the problem \( P_k \) obtaining the result \( Q_k \).

\( If (Q_k \text{ represents the problem } P_k \text{ solution}) \text{ then} \)

\( SOL_k = Q_k \)

\( Goto \text{ Step 5.} \)

\( else \)

\( @S_s \) creates a mobile subagent \( M_S \).

\( @S_s \) endows \( M_S \) with the information and data known about \( P_k \).

\( @S_s \) endows \( M_S \) with the information \( Q_k \).

\( @S_s \) based on the problem solving statement and the information detainted about the other hosts establishes \( M_S \) itinerary \( I_S \).

\( @S_s \) launches \( M_S \) to the first host specified in the itinerary \( I_S \).

\( EndIf \)

\( else \)

\( @S_s \) creates a mobile subagent \( M_S \).

\( @S_s \) endows \( M_S \) with the knowledge known about the problem \( P_k \).

\( @S_s \) establishes \( M_S \) itinerary \( I_S \).

\( @S_s \) launches \( M_S \) to the first host specified in the itinerary \( I_S \).

\( EndIf \)

**Step 3**
While (solution of the $P_k$ problem is not obtained) do

@ The current host $H_c$ tries to find a submitted agent capable to process the knowledge contained in the mobile subagent $M_S$ body.

If (exists at least one capable submitted agent) then

@ $H_c$ selects the best-fitted agent $A_g$ capable to processes the problem.
@ $H_c$ transmits the knowledge transported by $M_S$ to $A_g$.
@ $A_g$ processes the received knowledge obtaining the result $Q_k$.
@ $A_g$ transmits the obtained result $Q_k$ to the host $H_c$.
@ $H_c$ endows the mobile subagent $M_S$ with the new knowledge $Q_k$.

If (the problem $P_k$ solution is obtained) then

@ Let $SOL_k$ be the solution of the problem $P_k$.
Goto Step 4.

EndIf

else

If ($M_S$ itinerary $I_S$ doesn’t contain an unvisited host) then

@ $H_c$ establishes (based on the problem solving statement and the information known about the other hosts from the system) a new host $H_q$ unvisited by $M_S$.

$I_S = I_S - \{H_c\}$.
$I_S = I_S \cup H_q$.

@ $H_c$ launches the mobile subagent $M_S$ to the host $H_q$.

EndIf

@ $H_c$ transmits $M_S$ to the next host specified in $M_S$ itinerary $I_S$.

EndIf

EndWhile

Step 4

@ $M_S$ transports the problem $P_k$ solution $SOL_k$ to $Ss$ ($M_S$ is launched to $Ss$ by the current host).

Step 5

@ $Ss$ transmits the solution $SOL_k$ to the problem sender.

EndCooperativeMedicalProblemSolving.

The static subagent $Ss$ of the agent $MA$ will solve the diagnosis problem $P_k$, if it has the necessary specialization and capacity. If $Ss$ cannot solve the problem $P_k$
(doesn’t have the necessary capability and/or capacity), then it will create a mobile subagent $M_S$, that is endowed with the knowledge (information and data) known about the problem $P_k$ (initial problem solving statement) and an itinerary $I_S$. As examples of knowledge that can be detained initially about a diagnosis problem (diagnosis of a patient’s illness), we mention: the illness symptoms descriptions, the history of the symptoms, the patient’s previous illnesses evolution and the patient’s allergy to some medicines. The itinerary of an ICMA mobile subagent consists in the hosts that can be visited by the subagent. Each host included in the itinerary is estimated that have submitted agents “capable” (have the necessary capability and capacity) to processes the problem. The purpose of a host visiting consists in the processing of the knowledge detained about the problem (knowledge detained in the problem solving statement) by one or more agents submitted to the host. After a problem processing, a result is obtained (new knowledge) that can represent the problem solution (the identified illness and the established diagnosis to cure the illness) or may help the agents in following processing of the problem. A problem solving statement is changing during a problem solving process, in order to come closer to the problem solution. The itinerary of a mobile subagent is established based on the problem that must be solved and the knowledge detained about the hosts from the diagnosis system. A medical ICMA agent may collect information about the system from the host to which it is submitted. The hosts in the itinerary of a mobile subagent are ordered based on the problem processing capabilities of the agents submitted to the hosts. The first host specified in the itinerary is estimated that contains the best-fitted agent (agents) capable to process the problem. Initially the mobile subagent is transmitted to the first host specified in its itinerary. The mobile agent will visit different hosts until the transmitted problem is solved. The information about a problem solving statement (8), detained in a mobile subagent body, is understandable to the physicians and artificial agents (the information is grouped based on the specifics of the information) and the hosts may extract easily the knowledge that must be transmitted to submitted agents. Each group of information has an identifier that allows the identification of the group of information.

The knowledge detained in a mobile subagent’s body contains different information and data obtained during a diagnosis problem solving process. As examples of knowledge contained in a mobile subagent body, we mention: the specification of the necessity to use a physician in the problem solving, the maximum allowed time for the problem solving, the necessary problem solving specialization, the illness symptoms descriptions, medical analyses results, different observations related to the illness, supposed illnesses etc. An agent who processes a problem transported by a mobile subagent agent may add, retract or modify the transported knowledge.

As examples of knowledge that can be added onto a mobile subagent $M_S$ body, by an agent $Ag_x$ ($Ag_x \in MD$) submitted to a host $H_f$ ($H_f \in H$), we mention:

- a new supposed illness. $Ag_x$ supposes that the patient has an illness;
• new questions that must be answered by other agents. $Ag_x$ is limited in knowledge he is specialist in certain medical domains;
• the results of some medical analyses.

As examples of knowledge that can be eliminated from a mobile subagent $M_S$ body by an agent $Ag_x$ ($Ag_x \in MD$) submitted to a host $H_f$ ($H_f \in H$), we mention:
• useless information. Some information from $M_S$ body is not relevant in the diagnosis process;
• a supposed illness. $Ag_x$ demonstrates that the patient does not have the supposed illness written onto $M_S$ body.

As examples of knowledge that can be modified onto a mobile subagent $M_S$ body by an agent $Ag_x$ ($Ag_x \in MD$) submitted to a host $H_f$ ($H_f \in H$), 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 illnesses.

In the case of a visitor mobile subagent, the host will verify if it has a submitted agent that can solve or process the problem carried by the mobile subagent. If at least one capable agent is found, then the best-fitted agent is selected, and the knowledge carried by the mobile subagent is transmitted to this agent. If the host does not find a capable agent, then the mobile subagent is transmitted to the next host specified in the mobile subagent itinerary. If the host does not find a capable agent, and the mobile subagent itinerary does not contain an unvisited host, then the host will introduce a new host in the mobile subagent itinerary.

The Algorithm – Problem Allocation for Solving describes the process of finding the best-fitted agent by the host $H_c$, capable to processes the problem $P_k$ carried by an ICMA mobile subagent $M_S$. To establish the best-fitted agent capable to process the problem $P_k$, the host $H_c$ announces the problem to a set $SUB$ of submitted agents. In the establishment of the agents to which the announcement $An$ should be sent, $H_c$ uses its knowledge detained about the submitted agents and the knowledge detained in $M_S$ body. As an example of information that can be used in the establishment of the agents to which a problem announcement should be sent we mention the specification in the body of the mobile subagent of the problem solving by a physician (the problem is considered to be difficult). Based on this information, $H_c$ will send the problem announcement $An$ to submitted physicians only. A problem announcement may be answered by more agents that have received the announcement. Based on the responses parameters values the host will choose the best-fitted agent.

Algorithm – Problem Allocation for Solving

{IN: $P_k$ - the medical problem}

{OUT: $Ag_x$ the agent selected for the problem $P_k$ processing}
Step 1
@H_c extracts the knowledge detained about the problem P_k from M_S body.

Step 2
@H_c establishes the problem P_k announcement An.
@H_c establishes the submitted agents SUB to which An should be sent.

Step 3
If (SUB ≠ ⊘) then
   @H_c transmits the announcement An to the selected agents SUB.
   While (the waiting time to the announcement An is not expired) do
      @H_c receives and evaluates the bids to the announcement An.
   EndWhile
   @H_c selects the best-fitted agent Ag_x capable to process the problem P_k.
   If (\{Ag_x\} ≠ ⊘) then
      @H_c transmits the knowledge about P_k carried by M_S to Ag_x.
   else
      @”There is no capable submitted agent to processes the problem P_k.”
   EndIf
else
   @”There is no capable submitted agent to processes the problem P_k.”
EndIf
EndProblemAllocationForSolving.

P_k problem announcement An emitted by a host H_v (H_v ∈ H) has the form (3).

⟨Id_g; Knowledge_g; Eligibil_g; Bid_g; Time_g⟩.

(3)

Id_g represents the P_k problem announcement identifier. Knowledge_g represents the knowledge detained about the transmitted P_k problem (contains the problem solving statement – information obtained during the problem processing). Eligibil_g specifies the criteria of bid acceptance. As an example of eligibility criteria, we mention the specification to use a physician in the problem processing (P_k is considered to be difficult). Bid_g tells to the contacted agents what information must be provided with the bid. Returned bid specifications gives to the announcement sender host a basis for comparing bids received from more agents. As an example of information that can be provided with the bid specification, we mention the estimated problem solving time. Time_g is the deadline for receiving bids.
A response of an agent $Ag_x$ ($Ag_x \in MD$) to the $P_k$ problem announcement $An$ has the parameters (4).

$$\langle \text{Address}_f; Id_f; \text{Resp}_f; \text{Capab}_f; \text{Capac}_f; \text{Relev}_f \rangle. \quad (4)$$

$\text{Address}_f$ represents $Ag_x$ address. $Id_f$ represents the announcement $An$ identifier. $\text{Resp}_f$ represents the bid to the $P_k$ problem solving (acceptance or rejection). $\text{Capab}_f$ represents the capability of $Ag_x$ (the specialization that can use $Ag_x$ in the $P_k$ problem processing). $\text{Capac}_f$ represents the processing capacity of $Ag_x$. $\text{Relev}_f$ specify the importance of the $P_k$ problem processing by $Ag_x$ (the measure in which the $P_k$ problem processing by $Ag_x$ approaches the solution).

In the following, a cooperative problem solving process by more agents is described formally. The general case is presented, when a static subagent cannot solve an overtaken problem; from this reason he must cooperate with other agents in order to solve the problem.

A Cooperative Problem Solving Process

@ The problem transmission for solving

$P_z \Rightarrow Ss$.

@ The creation of an ICMA mobile subagent

$Ss \rightarrow M_j(P_z; I_j = \{H_i, H_r, \ldots, H_k\})$.

@ The cooperative solving of the problem

$M_j(P_z; I_j) \Rightarrow \{H_i[A_i], H_r[A_r], \ldots, H_k[A_k]\}$.

$\text{End Cooperative Problem Solving Process}$.

$P_z$ represents the problem that must be solved. $Ss$ represents the static subagent of an ICMA agent who has overtaken the problem $P_z$ for solving. $M_j$ represents an ICMA mobile subagent created by $Ss$. $I_j$ represents $M_j$ itinerary (specifies the hosts $H_i, H_r, \ldots, H_k$, estimated that must be visited in order to solve $P_z$). $A_i, A_r, \ldots, A_k$ represent the sets of agents submitted to the hosts $H_i, H_r, \ldots, H_k$, that have contributed to $P_z$ processing. The set $A_v$ of agents at a host $H_v$ that contribute to a problem processing can be the empty set. $|A_v|$ denotes the number of agents in the set $A_v$. $|A_v| = 0$ (if during the problem processing any agent did not contribute at the host $H_v$) or $|A_v| \neq 0$ (if at least one agent has contributed at the host $H_v$ to the problem processing).

In the MDS system each agent has a role. The notion role is defined in [2, 8]. A role in a multiagent system defines the manner in which the agents that take over the role contribute to the problem solving. An agent who takes over a role must have a set of specializations, which allows the agent to fulfil its role in the multiagent system. In the MDS system there are two roles (Figure 4): by diagnosis problems processing denoted process and decision making about the diagnosis problems processing denoted decision. An agent who takes over the process role will contribute to
the problems processing during its live cycle. The medical ICMA agents, physicians
and medical expert system agents have the process role. An agent who takes over
the decision role will contribute to the problems solving during its live cycle, by
deciding what to do with the overtaken problems (in the case of an overtaken prob-
lem they will decide to which agent it should be sent for processing). The medical
ICMA agents and the hosts have the decision role. The medical ICMA agents have
both roles (decision and process).

Fig. 4. The roles in the LMDS system

The knowledge used by an agent must be represented using a knowledge repre-
sentation language understandable by the agent (the agent can solve problems using
the knowledge). In a multiagent system ontologies (dictionaries of used terms) must
be used necessary in specifying the used knowledge meanings. The papers [2, 8]
define the notions knowledge representation language and ontology. A medical on-
tology represents a dictionary of medical terms [40]. As examples of developed
medical ontologies described in the literature, we mention: GALEN [34], UMLS [35],
OntHoS [36], LinkBase [37], TAMBIS [38] and GENE [39].

Figure 5 presents the knowledge and rationality distribution in the MDS system
between the system’s members. \(PH_1, PH_2, \ldots, PH_c\) represent the physician mem-
biers of the system. \(Ar_1, Ar_2, \ldots, Ar_b\) represent the artificial agent members of the
system. Each physician can solve problems based on the medical knowledge s/he
detains. Each artificial agent can solve problems based on a knowledge base that
contains the specializations of the agent. A medical specialization detained by an
artificial agent is represented as a set of rules by the form specified in (7) and (8)
presented in Section 3.3.

The knowledge of the artificial agents and the knowledge (information and data)
detained about the diagnosis problems solving statements are represented symboli-
cally (symptoms of the illnesses, syndromes of the illnesses etc. – are represented
using words in a natural human language) and numerically (medical analysis re-
results – some parts of them may have numerical representation). The knowledge
detained about a diagnosis problem solving statement has the form (9). If a diag-
nosis problem is transmitted for solving by an ICMA mobile subagent, then the
knowledge about the problem solving statement is detained in the subagent body.
The knowledge detained in a problem solving statement (9) is “understandable”
(problems can be solved using the knowledge) to the physicians and to the artificial agents. The artificial agents can use the detained rules in the processings in the form specified in (7) and (8). The precondition of a rule may fit some of the knowledge detained in a problem solving statement. The postcondition of a rule specifies the processing that can be realized to the knowledge detained in a problem solving statement. In an LMDS system composed from a large number of agents, where a large quantity of medical knowledge is used, ontologies can be defined that may help the physicians and/or artificial agents during their operation. For example, we mention an ontology that describes illnesses in a language (English for example). Such an ontology may help the physicians during the diagnosis establishment.

3.3 Simulations and Experiments

We have realized simulations of an LMDS system denoted \textit{DIAG} (5). \(A_{gm}\) represents a medical ICMA agent specialized in general medicine. The specialization of \(A_{gm}\), \(Spec(A_{gm}) = S_m\) is detained by its static subagent \(S_s\). \(A_{gc}\) represents an expert system agent with a specialization \(Spec(A_{gc}) = S_c\) that represents diagnosing knowledge in cardiology. \(A_{gu}\) represents an expert system agent with a specialization \(Spec(A_{gu}) = S_u\) that represents diagnosing knowledge in urology. \(H_1\) and \(H_2\) represent the hosts from the \textit{DIAG} system. \(A_{gm}\) and \(A_{gu}\) are submitted to \(H_1\). \(A_{gc}\) is submitted to \(H_2\).
\[ \text{DIAG} = \text{MD} \cup H, \]
\[ H = \{H_1, H_2\}, \]
\[ \text{MD} = \{\text{Ag}_m, \text{Ag}_c, \text{Ag}_u\}. \]
\[ \text{Spec(DIAG)} = \langle \text{Spec(\text{Ag}_m)}; \text{Spec(\text{Ag}_c)}; \text{Spec(\text{Ag}_u)} \rangle. \quad (5) \]

\( \text{Ag}_m, \text{Ag}_c \) and \( \text{Ag}_u \) may processes (add, retract or modify) the knowledge detained in an ICMA mobile subagent body. For doing such operations, each of the agents \( \text{Ag}_m, \text{Ag}_c \) and \( \text{Ag}_u \) uses a specialization that contains a set of rules.

Let \( R \) (6) be a set of rules detained by an agent member of the \( \text{DIAG} \) system. \(|R|\) denote the number of rules in the set \( R \) of rules; \(|R| = w \) (\( w \) is a natural number).

\[ R = \{R_1, R_2, \ldots, R_w\}. \quad (6) \]

A rule \( R_k \) (\( R_k \in R \)) has the form (7).

\[ \langle \text{No}_k; \text{Domain}_k; \text{Type}_k \rangle \]
\[ \text{Prec}_k \rightarrow \text{Post}_k. \quad (7) \]

\( \text{No}_k \) represents the \( R_k \) rule identifier (each rule detained by an agent has a unique number as identifier). \( \text{Domain}_k \) represents the medical domain in which the \( R_k \) rule allows medical knowledge processing. \( \text{Type}_k \) represents the type of the \( R_k \) rule. Each rule has a single type (one of the following): add (for adding knowledge), retract (for retracting knowledge) or modify (for modifying knowledge).

\( \text{Prec}_k \) represents the \( R_k \) rule precondition. \( \text{Prec}_k \) specifies the conditions that must be verified in order to apply the \( R_k \) rule. \( \text{Post}_k \) represents the \( R_k \) rule postcondition. \( \text{Post}_k \) specify the changes (adding, retracting or modifying) that must be made on the knowledge specified in the \( R_k \) rule precondition.

The precondition and postcondition of each rule may have some of the parameters (8).

\[ \langle \text{Symp}_k[1]; \text{Syd}_k[2]; \text{Anly}_k[3]; \text{Past}_k[4]; \text{Il}_k(\text{P}_k)[5]; \text{Clas}_k[6] \rangle. \quad (8) \]

\( \text{Il}_k \) represents an illness. \( \text{P}_k \) represents the probability of occurrence of the \( \text{Il}_k \) illness. \( \text{Symp}_k \) represents the symptoms of the \( \text{Il}_k \) illness. \( \text{Syd}_k \) represents the syndromes of the \( \text{Il}_k \) illness. \( \text{Anly}_k \) represents medical analysis results necessary in the \( \text{Il}_k \) illness identification. \( \text{Past}_k \) represents illnesses that have appeared in the past (illnesses that may influence the occurence of \( \text{Il}_k \) illness). \( \text{Clas}_k \) contains the specification of different classes of illnesses in which it is assumed that the \( \text{Il}_k \) illness is included.

In each rule some parameters of the postcondition and/or precondition may be missing. Each parameter in (8) has a unique identifier (a natural number between 1 and 6) in the parameter list. For example, the parameter \( \text{Syd}_k \) that has associated
the number 2, specifies that the parameter value (values) contain the description of 
one (more) syndrome (syndromes) of the $I_{S_k}$ illness.

A diagnosis problem $P_k$ solving statement may have some of the parameters (9).

$$\langle |\text{Symp}_k||1|; |\text{Synd}_k||2|; |\text{Anal}_k||3|; |\text{Past}_k||4|;$$
$$|\text{Sup}_k(|P_{s_k}|)||5|; |\text{Clas}_k||6|; |\text{Demons}_k(|P_{d_k}|)||7|\rangle.$$ (9)

If a problem $P_k$ is transported by an ICMA mobile subagent denoted $M_S$, then 
the problem solving statement is detained in the $M_S$ body. Symp$_k$ represents the 
patient’s illness symptoms. Synd$_k$ represents the patient’s illness syndromes. Anal$_k$
represents different analysis results realized in order to identify the patient’s illness. Past$_k$
represents patient’s illnesses from the past. Sup$_k$ represents supposed illnesses of the patient. P$S_k$
represents the probabilities of occurrence of the supposed illnesses. Demons$_k$ represents demonstrated illnesses of the patient. P$d_k$
represents the probabilities of occurrence of the patient’s demonstrated illnesses.
A supposed illness is a demonstrated illness with a low probability of occurrence. 
During a diagnosis process the agents may change the probability of occurrence of an illness specified in a parameter list. For example, a supposed illness may become 
demonstrated illness after performing some medical analyses (the probability with 
which the illness occurrence is supposed has been increased). Clas$_k$ contains the 
specification of different classes of illnesses in which it is assumed that the patient’s 
illness is included. Each parameter in (9) has a unique identifier (a natural number 
between 1 and 7), that help the agents establish the rules that can be used in the 
processing (makes easier the rules precondition matching, when some parameters in 
a mobile subagent body have no value).

If in a problem solving statement more demonstrated and/or supposed illnesses 
are specific, to each illness a unique natural number is attached as identifier (each 
ilness identifier is different in a problem solving statement). In this situation, to 
each information in the parameter list the illness identifier is attached, that helps 
the agents identify to what illness the information is attached. As an example, we 
consider that in the case of a patient, two illnesses denoted $I_1$ and $I_2$ are 
demonstrated. To the illness $I_1$ the identifier 1 is attached. To the illness $I_2$ the 
identifier 2 is attached. For example, $|S_a : 1,S_b : 1 : 2,S_c : 2||1|$ specifies the first 
parameter (specified by [1]) in a problem solving statement (9) (the first parameter 
specifies illness symptoms); $S_a$ specifies a symptom that is associated with the illness 
$I_1$ (identifier :1 is attached to $S_a$), $S_b$ specifies a symptom that is associated with both 
ilnesses $I_1$ and $I_2$ (identifiers :1 and :2 are attached to $S_b$) and $S_c$ specifies a 
symptom that is associated with the illness $I_2$ (identifier :2 is attached to $S_c$).

In the following, solving of a cardiology related illness problem $P_{\text{card}}$ by the 
$DIAG$ system is described (the problem $P_{\text{card}}$ solution $SOL_{\text{card}}$ that must be 
obtained represents the identified illness). Initially $P_{\text{card}}$ contains the problem initial 
description (different information and data detained initially about the patient’s illness).
Problem Solving Description

Step 1

- The problem \( P_{\text{card}} \) is overtaken by the static subagent \( S_s \) of \( A_{g_m} \) (\( A_{g_m} \) is the only ICMA agent in the \( \text{DIAG} \) system).

Step 2

- \( S_s \) processes the problem \( P_{\text{card}} \) using the specialization \( S_m \). \( S_s \) makes some observations \( Q_{\text{gen}} \) related with the patient’s illness (\( Q_{\text{gen}} \) does not represent solution of the problem \( P_{\text{card}} \). \( S_s \) cannot solve the problem \( P_{\text{card}} \) because it does not have the necessary specialization).
- \( P_{\text{card}} = P_{\text{card}} \cup Q_{\text{gen}} \).
- \( S_s \) creates a mobile subagent \( M_S \) which is endowed with the knowledge \( P_{\text{card}} \) and the itinerary \( I_S = \{H_1, H_2\} \).
- \( S_s \) launches \( M_S \) to the first host \( H_1 \) (\( H_1 \in I_S \)) specified in the \( M_S \) itinerary \( I_S \).

Step 3

- \( H_1 \) cannot find any agent capable of processing the problem \( P_{\text{card}} \).
- \( I_S = I_S - \{H_1\} \).
- \( H_1 \) launches \( M_S \) to the next host \( H_2 \) (\( H_2 \in I_S \)) specified in the \( M_S \) itinerary \( I_S \).

Step 4

- \( H_2 \) establishes the agent \( A_{g_c} \) which can process \( P_{\text{card}} \).
- \( H_2 \) transmits the knowledge carried by \( M_S \) to \( A_{g_c} \).
- \( A_{g_c} \) solves the problem \( P_{\text{card}} \), using \( S_c \), obtaining the solution \( \text{SOL}_{\text{card}} \).
- \( A_{g_c} \) transmits the problem solution \( \text{SOL}_{\text{card}} \) to the host \( H_2 \).
- \( H_2 \) endows \( M_S \) with the problem solution \( \text{SOL}_{\text{card}} \).
- \( I_S = I_S - \{H_1\} \).
- \( H_2 \) launches \( M_S \) to \( S_s \).

Step 5

- \( S_s \) transmits the problem solution \( \text{SOL}_{\text{card}} \) to the problem sender.

EndProblemSolvingDescription.

\( P_{\text{card}} = \{ \text{a cardiology related illness description} \} \).

\( \text{SOL}_{\text{card}} \) represents the solution of the problem \( P_{\text{card}} \).

\( \text{SOL}_{\text{card}} = \{ \text{the identified cardiology related illness} \} \).
The problem $P_{\text{card}}$ solving process can be described as follows (10):

$$\text{Ag}_m(P_{\text{card}}; S_m) \Rightarrow \text{Ag}_c(P_{\text{card}} \cup Q_{\text{gen}}; S_c) \Rightarrow \text{SOL}_{\text{card}},$$

$$\text{DIAG}(P_{\text{card}}; S_m, S_c) \Rightarrow \text{SOL}_{\text{card}}. \quad (10)$$

$S_s$ ($S_s$ is the static subagent of $\text{Ag}_m$) processes $P_{\text{card}}$ using the specialization $S_m$ obtaining the knowledge $Q_{\text{gen}}$. $\text{Ag}_c$ processes $P_{\text{card}} \cup Q_{\text{gen}}$ using the specialization $S_c$ obtaining the solution $\text{SOL}_{\text{card}}$. $Q_{\text{gen}}$ represents different general observations related to the patient’s illness elaborated by $S_s$. In the $P_{\text{card}}$ problem solving the $\text{DIAG}$ system has used the specializations $S_m$ and $S_c$.

Simulations show the correctness of the problem solving by the $\text{DIAG}$ diagnosis system. The simulations were realized for the diagnosis of usual illnesses (identified by physicians specialized in general medicine), cardiology and urology related illnesses. The diagnosis system can solve a diagnosis problem, if it has the necessary medical problem solving knowledge distributed between the member agents. The accuracy of the diagnostics elaborated by the $\text{DIAG}$ system depends on the accuracy of information and data specified in the rules preconditions and postconditions (the rules are established by human specialists). In cooperation with physicians, a knowledge engineer establishes the medical diagnosing knowledge that is retained as rules. The form of the rules specified by (7), (8) and the problem solving statement description specified by (9), can be adapted to the specific features of the medical problems (what medical information and data must be processed during the diagnostic processes) that must be solved by the agents. For example, during a diagnosis process the history of the symptoms of an illness can be used. In this case, there must exist rules detained by agents, whose precondition and/or postcondition contain history of symptoms. The problem solving statement will contain such information. To increase the elaborated diagnostics accuracy the artificial agents must be endowed with learning capability. They must adapt or retract the rules that have some uncertainties (some erroneous and/or missing data).

### 3.4 Motivations and Advantages of the LMDS System

One of the most important directions of research related with the medical agents consists in the development of large-scale medical diagnosis systems [7, 9, 13]. Many of the existent medical knowledge, medical information and data detained about patients (medical history for example) are distributed. Medical decisions elaborations may involve solving of different problems. Distributed medical information and data must be collected, analyzed and processed. For many of these problem solvings, the agent-based approaches are the best-fitted solutions. The agents can solve, based on their proprieties (autonomy, capability to perceive the environment, capability to execute actions in the environment, capability to learn autonomously, capability to assist pro-actively humans in the decisions elaboration, capability to communicate and cooperate in the problems solving) problems that cannot be solved by traditional medical systems (medical expert systems for example) [3, 5, 23].
The agents can solve problems using combinations of problem solving methods [25, 8]. A motivation of combination of more problem solving methods consists in the maximization of the methods advantages and minimization of their disadvantages. For example, an agent can be endowed with a component that uses neural networks and fuzzy inferences. As an example of a problem that can be solved using such a hybrid method we mention measuring of the cardiac function quantitatively and evaluating the motions of continuous cardiac muscle for detecting the asynery in the left ventricle, using X-ray photograms of the left ventricle [47]. Agents may integrate and extend different existing problem solving technologies [8, 23, 2]. The use of cooperating agents in problem solving has as advantage, namely the combination of the agents capabilities and capacities.

The medical diagnosing knowledge in the LMDS system is distributed between the agents (physicians and artificial medical agents) members of the system. Each host from the system detains information about a set of submitted agents, this helps in the establishment to which agents the overtaken problems should be sent for processing. A host also detains information about some other hosts members of the system. The problems that cannot be solved by the agents submitted to a host are transported for solving to other agents by ICMA mobile subagents. A mobile subagent migrates with an overtaken problem from host to host, until the problem is solved. ICMA mobile subagents can be used successfully in the solving of the problems, whose solving requires knowledge and/or resources distributed in the system.

In the LMDS system, the medical diagnosis problems are transmitted randomly for solving to the medical ICMA agents. The agents members of the system can solve problems simultaneously, each agent has specializations and resources that can be used in the problems processing. An agent may overtake more problems for processing depending on its specializations and capacity. Each problem overtaken by the system can be solved cooperatively by more agents members of the system.

The LMDS system can solve medical problems that can be broken into subproblems. A static subagent of an ICMA agent can solve some subproblems of an overtaken problem. The rest of the subproblems can be transmitted for solving by mobile subagents of the agent. Based on the obtained subproblems solutions the static subagent will form the solution of the problem. As an example of subproblem of a medical diagnosis problem, we mention a medical analysis necessary in increasing the accuracy of an illness identification. The medical analysis can be realized by a human medical specialist. As example of another subproblem we mention the recognition of the disorder of an internal human organ, based on different data obtained about the organ functioning. This subproblem can be solved by a specialized agent during the subproblem solving.

The artificial agents can be endowed with new medical specializations. Inefficient specializations can be eliminated or adapted. LMDS is an open system, each host may submit new agents. The hosts may assist physicians in their interaction with the system by translating the information transmitted to the physicians into a form understandable to the physicians. A physician may require knowledge necessary
in the problems solving from the host to which it is submitted. For example, the physician may require an illness description and a patient’s previous illnesses.

A physician and an artificial agent submitted to the same host can diagnose the same illness. The obtained solutions can be compared by the physician. The same solution obtained by the physician and the artificial agent increases the certainty in the correctness of the obtained solution. If the obtained solutions differ, the physician and the artificial agent must reanalyze the problem solving. The problem may be transmitted for solving to other agents. A problem solution will be established by the agents (human and artificial) who have participated in the diagnosis process. An obtained solution must be validated by a physician (physicians) specialized in the medical domain in which the identified illness (illnesses) is included.

4 CONCLUSIONS

Medical diagnostics elaborations often represent a naturally distributed and cooperative processes, which involves human medical specialists and different medical systems [2, 14, 23, 36, 45]. The results described in the literature prove that many medical diagnosis problems can be solved efficiently by large-scale medical multagent systems. The development of large-scale medical diagnosis systems represents an important recent research direction [7, 9, 13].

In this paper, we have proposed a cooperative hybrid large-scale medical diagnosis system, called LMDS (Large-Scale Medical Diagnosis System) with physicians and artificial agents (medical expert system agents and medical ICMA agents) as members. The proposed hybrid medical diagnosis system is a complex system. It is composed from physicians and artificial agents that cooperate in order to discover solutions of difficult medical diagnosis problems. Difficult medical cases are those in which identification of the illnesses and establishment the corresponding efficient treatments is difficult. The necessary knowledge for the problem solving in the LMDS system is distributed between the humans and agents members of the system. Each member of the system contributes to the problem solving depending on its detained knowledge. A contribution to a problem solving by a member of the system may make the problem following processing easier for other members. The system’s members cooperate in order to handle the complexity of the diagnosis establishment.

The agents called medical expert system agents have been developed in our previous works and applied for different medical problems solving [5, 6, 8, 10]. In previous works, a novel mobile agent architecture called ICMA (Intelligent Cooperative Mobile Agent Architecture) was developed. The ICMA architecture allows the creation of mobile agents; this partially eliminates disadvantages of recently developed mobile agents described in the literature [4, 7, 19]. Applications of the ICMA agents for problem solving based on genetic problem solving methods are presented in [20, 21, 22]. Medical ICMA agents represent agents with the ICMA architecture.
endowed with medical diagnosing knowledge. Some introductory elements about the medical ICMA agents were described in [9].

The LMDS system is not intended to substitute the physicians. In a diagnostic establishment, the system combines the physicians and artificial agents’ advantages related with their capabilities and capacities to elaborate medical diagnostics. Physicians may solve problems using their medical knowledge and intuition (the intuition is a specific property of human intelligence). However, they can solve difficult medical diagnosis problems that cannot be solved by artificial agents. The artificial agents cannot solve problems that are too different from known problems solving, and problems where difficult to handle uncertainties (some erroneous and/or unknown information and data) appear during solving. The artificial agents might analyze details that can be ignored by physicians. However, the artificial agents may help the physicians increase the elaborated diagnostics accuracy. As examples of information that can be ignored by physicians in a diagnostic establishment, and that can be verified by an artificial agent if the information exists in a medical data-base, we mention: the patient’s allergy to a medicine, the contraindications of a medicine, etc.

The next research includes the endowment of the ICMA agents with autonomous learning capability. ICMA mobile subagents may transmit useful information to their creator’s static subagents. Static subagents can learn from the received information, modifying the detained medical knowledge. The motivations of the possibility to endow an ICMA agent with autonomous learning capability consist in the ICMA agents’ increased communication capability [4], capability of the ICMA agents to transport knowledge to other agents [4], increased protection possibility of the ICMA agents against network sources and malicious hosts [19] and increased intelligence in operation [7].

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