THE ICMA AGENTS INTELLIGENCE

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Abstract

The development of software mobile agents that can solve intelligently difficult problems, represent an important research direction. There are few mobile agents described in the literature that can be considered intelligent. The difficulties in the endowment of the mobile agents with intelligence, has practical reasons related with the use of resources by the mobile agents in the network and at the hosts. In our previous works, a novel mobile agent architecture called ICMA was developed. There are analyzed advantages of the ICMA agents versus recently developed mobile agents. The proved advantages in previous works of the ICMA agents, consist in the increased communication capability and increased security. In this paper, we analyze the increased intelligence of the ICMA agents, which suggest their use for difficult problems solving in different domains. Researches realized in previous works, prove that agents with the ICMA architecture can be used for solving problems using evolutionary problem solving methods and medical diagnosis problems solving methods.

Keywords: agent architecture, mobile agent, intelligent agent, multiagent system, knowledge-based system, complex system, cooperative problem solving

1. Introduction

Agents and *multiagent systems* have applications in many domains [7, 8, 44, 46, 41, 45, 10, 17, 20]. The *software mobile agents* represent a class of agents that operate migrating in networks. The *mobile agents* represent a relatively new paradigm in the area of distributed programming and a useful supplement of traditional techniques like the Client/Server architecture [11, 12, 39, 43, 47]. Mobile agent technology has been applied to develop solving methods for various kinds of parallel and distributed computing problems [36].

Few realized mobile agents could be considered intelligent [5, 4, 6]. In previous works a novel intelligent mobile agent architecture called *ICMA* (*Intelligent Cooperative Mobile Agent Architecture*) was developed. The agents endowed with the *ICMA architecture* are called *ICMA agents*. *ICMA architecture* represents a combination of the static and mobile agent paradigms. The ICMA agents eliminate some disadvantages of the recently developed mobile agents. *ICMAE agents* (*Intelligent Cooperative Mobile Agent Architecture with Evolutionary Problem Solving Specializations*) represent a novel class of agents, developed in our previous researches. *ICMAE agents* are agents with the *ICMA architecture*, endowed with evolutionary problem solving specializations [32, 23, 22]. *Medical ICMA* agents represent a novel class of medical agents endowed with medical diagnosis capability [52]. *Medical ICMA agents* are agents with the *ICMA architecture* endowed with medical knowledge.

In this paper, the intelligence of the *ICMA agents* and the intelligence of the multiagent systems formed by ICMA agents are analyzed. The paper in four sections is structured. Section 2 analyses the disadvantages of the recently developed mobile agents described in the literature; are presented developed mobile agents. Section 3 describes the ICMA architecture; are presented applications of the ICMA agents; is analyzed the ICMA agents intelligence and the intelligence of the ICMA multiagent systems. In the Section 4 are presented the conclusions of the paper.

2. Applications of the software mobile agents

In the literature there are described many developed mobile agents applied for different problems solving. *TRACY* [5, 4, 6] and *OnkoNet* [49] mobile agents are representative in this sense. *Tracy* agents developed at „Friedrich Schiller" University of Jena [5, 4, 6] represent an important development of mobile agents. A basic propriety of the *TRACY* agents consists in their capability to optimize the migration.

OnkoNet mobile agents have been used successfully for patient-centric medical problems solving [49]. In the paper [49], is introduced the notion *ubiquitous healthcare*, addressing the access of health services by individual consumers applying to mobile computing devices. This access requires different medical knowledge about the individual health status. The *OnkoNet* mobile agent architecture involves architectures on the macro-level and micro-level as well as cooperation protocols. *OnkoNet* mobile agents prove that mobile agent can be useful for patient-centric problems solving in the medical domains.

The main disadvantages of the mobile agents consist in their limited [28, 29, 20]: intelligence, security and communication capability. These disadvantages have practical motivations, resulting from the basic proprieties of the mobile agents, like: autonomy in migration, distributed and asynchronous operating manner.

The communication between mobile agents at different hosts is difficult [14]. The mobile agents migrate during their operation from host to host. Is difficult to establish where a mobile agent is at a certain moment of time. The difficulties in communication make difficult the endowment of the mobile agents with cooperation capability. It is usually assumed that the mobile agents have only a very limited or even no intelligence [14, 16, 18]. In many situations, the multiagent systems formed by cooperative mobile agents are considered intelligent. The mobile agents' intelligence is considered at the level of the multiagent system in which they operate.

The security solutions in mobile multiagent systems must include the protection of the hosts and the protection of the mobile agents [48]. The main disadvantage of the mobile agents consists in their limited security in the network and against the hosts. The hardest among all security issues raised by mobile agents consists in the protection of the agents against the hosts on which they are executing on [50, 51]. Once a mobile agent has arrived at a malicious host, little can be done to stop the host from treating the agent as it likes. An efficient protection mechanism, of a mobile agent against a host, should provide code and execution integrity, solutions for computing with secrets and prevention from denial of service attacks against agents. Prevention from an unauthorized data disclosure is made harder by the fact that a set of hosts may collaborate in the fraud.

3. Intelligent ICMA agents

3.1. ICMA architecture description

In our previous researches, a novel mobile agent architecture called *ICMA* (*Intelligent Cooperative Mobile Agent Architecture*) was developed [16, 18]. The purpose of the study was to develop a mobile agent architecture, which allows the creation of mobile agents that can solve intelligently problems. Disadvantages of recently developed mobile agents, which confirm the necessity of the development of novel intelligent mobile agent architectures, are presented in [28, 29, 20].

An agent denoted *MA*, endowed with the *ICMA architecture* consists of two parts, a static subagent denoted *Sp* and a mobile part denoted *Mp*. *Sp* creates the mobile subagents that form the mobile part of *MA*. The mobile subagents operate as the mobile agents described in the literature, they are responsible for the problems solving. Figure 1 presents an *ICMA* mobile agent. $Mp = \{Mp_1, Mp_2,..., Mp_v\}$ represents the mobile part of the agent. $Mp_1, Mp_2,..., Mp_v$ represent the mobile subagents launched for problems solving at the hosts $H_1, H_2,..., H_a$ distributed in the network. $P_1, P_2,..., P_s$ represent the problems transmitted for solving to *Sp*.

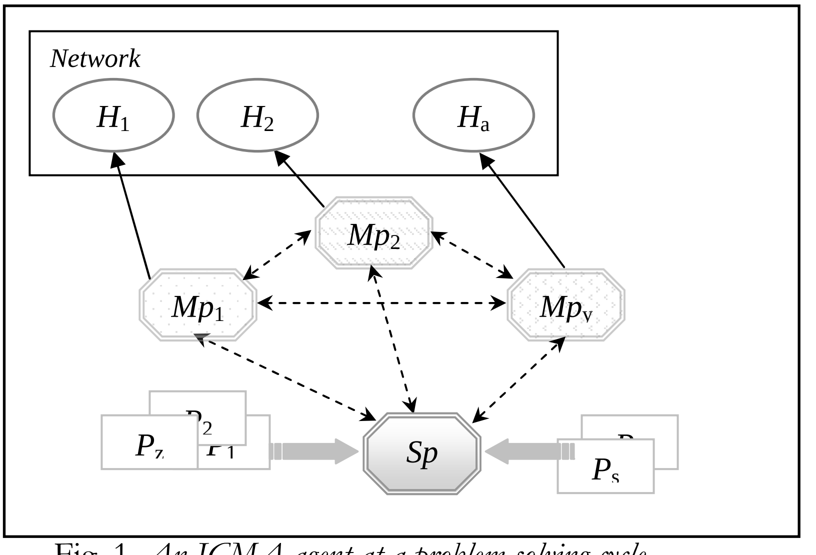

Fig. 1. *An ICMA agent at a problem solving cycle*

The algorithm *Problem Solving by an ICMA Agent* describes briefly an *ICMA* agent operation at a problem solving cycle. The detailed description of the algorithm can be found in [16, 18]. A problem solving cycle consists in overtaking and solving of a set $P = \{P_1, P_2,..., P_k\}$ of problems. $So = \{So_1, So_2,..., So_k\}$ represent the $P_1, P_2,..., P_k$ problems solutions.

Algorithm - *Problem Solving by an ICMA Agent*
{IN : $P_1, P_2,..., P_k$ - the problems transmitted for solving}
{OUT : $So_1, So_2,..., So_k$ - the problems $P_1, P_2,..., P_k$ solutions}
Step 1 - The problems overtaking for solving.
@*Sp* overtakes the problems $P_1, P_2,..., P_k$ transmitted for solving.
Step 2 - The problems solving establishment.
@*Sp* establishes $P_1, P_2,..., P_k$ solving by a set $Mp_1, Mp_2,..., Mp_v$ of mobile subagents.
@*Sp* launches $Mp_1, Mp_2,..., Mp_v$ for problems solving in the network.
Step 3 - The problems solving.
@$Mp_1, Mp_2,..., Mp_v$ solve the overtaken problems. The obtained results by $Mp_1, Mp_2,..., Mp_v$ are transmitted to *Sp*.
Step 4 - The transmission of solutions to the problems' sender.

@If is necessary, *Sp* processes the received results, the obtained solutions are transmitted to the sender of the problems P_1, P_2,..., P_k.

EndProblemSolvingICMAAgent.

3.2. Applications of the ICMA architecture

Performance evaluation of the mobile agents remains a difficult task, mainly due to the characteristics of mobile agents such as distributed and asynchronous execution, autonomy and mobility [38, 2, 15, 40]. In the papers [16, 18], there has been presented simulation results of *ICMA* agents. The purposes of the simulations' were to analyze how the number of created mobile subagents by a static subagent influences the problems solving time. The simulations have been performed for different sets of problems with different necessary solving time, different overloading degree of the hosts, using different number of created mobile subagents. The obtained simulation results [16, 18] show, that the performance of an *ICMA* agent that use more mobile subagents (between 2 and 12 mobile subagents - used in the simulations), is higher than the performance of the same *ICMA* agent that uses a single mobile subagent in the solving of the same set of problems (there are realized simulations for problems sets composed between 40 and 80 problems).

Evolutionary computation represents a relatively new field of the *Artificial Intelligence* [1, 9, 13, 37]. Methods based on evolutionary computation can be used for many problems solving [31]. *Evolutionary learning techniques* represent learning techniques based on methods of evolutionary computation. Multiagent systems that use evolutionary learning techniques, in order to reorganize their structure, with the purpose to solve more efficiently problems are presented in [21, 24, 25, 3]. *ICMAE* (*Intelligent Cooperative Mobile Agents with Evolutionary Problem Solving Capability*) represents a novel class of evolutionary agents [32, 23, 22]. *ICMAE* agents can solve problems using methods based on evolutionary computation [32, 23, 22]. The advantage of the *ICMAE* agents versus the evolutionary static agents, consist in the problems solving, using efficiently the existent resources distributed on the network.

Medical ICMA agents represent a novel class of medical agents [52]. The *medical ICMA agents* are agents with the *ICMA architecture*, endowed with medical knowledge. Advantages of the medical *ICMA agents* versus the *OnkoNet agents* consist in the increased [52]: intelligence and security in operation.

3.3. The intelligence of the ICMA agents

The advantages of the *ICMA agents* consist in their increased: communication capability [16, 30] and security [33]. These advantages are relevant to most of the recently developed mobile agents, like *Tracy* [5, 4, 6] and *OnkoNet* [49]. Other advantages of the ICMA agents consist in the capability to allocate problems for solving in large-scale networks [16]. In the following there are analyzed these advantages. Oslo is demonstrated the increased intelligence of the *ICMA agents* and the increased intelligence of the *ICMA multiagent systems* (multiagent systems composed from *ICMA agents*).

The ICMA agents' communication capability

The subagents of the same *ICMA agent* can communicate [16, 30]. Mobile subagents at the same host can communicate directly. The static subagent's address is not changing during the mobile agent's life cycle. Each mobile subagent transmits a message that contains the current host's address to the static subagent when it arrives to a host. Each mobile subagent communicates when it leaves a host. However, the static subagent can communicate with each mobile subagent that is at a host. Each mobile subagent at a host can communicate with the static subagent. When a mobile subagent wants to communicate with a mobile subagent at another host, it transmits the message to the static subagent. The static subagent will forward the message to the target mobile subagent, when the target mobile subagent is at a host. A mobile subagent can communicate with another mobile subagent, even if the target mobile subagent migrates in the network at the time of transmission. The source mobile subagent transmits the message to the static subagent, the static subagent transmits the message to the target mobile subagent when this agent arrives to a host.

ICMA agents can communicate with each other via their subagents [16, 30]. Mobile subagents of different mobile agents at a host can communicate directly. Static subagents can communicate directly. If mobile subagents of different mobile agents at different hosts want to communicate, they can use as mediator in the communication the static subagents which have created them.

The protection of the ICMA agents

An *ICMA agent's* body that migrates in the network consists in the mobile subagents that solve the problems. A network source or a host can access only some of the mobile subagents; it does not have a global view about all the operating mobile subagents. If some mobile subagents are lost, the rest of the mobile subagents are able to solve the overtaken problems. When a mobile subagent does not need a specialization in the following problems solving, then it can leave the specialization. However, the mobile subagent launched to the next host is smaller, contains less data and code that could be used or modified by network sources and hosts. The transmitted quantity of data and code in the mobile part of a mobile agent decrease in time during a problems solving cycle.

Each specialization of a mobile subagent is encrypted using a different encryption algorithm. When the mobile subagent arrives to a host, it transmits the host's address to the static subagent. The static subagent transmits to the host how to decrypt the specializations that must be used in the problems solving. However, only the specializations and data necessary in the problems solving are understandable to the host.

A static subagent can check whether if its mobile subagents are modified during their journey. When a mobile subagent arrives at a host, it transmits the host's address and its checksum to the static subagent. However, the static subagent can verify, based on the mobile subagent's checksum, if the mobile subagent is modified. The static subagent has each mobile subagent's itinerary, however, it can verify if each mobile subagent visit all the hosts specified in its itinerary. In the case of a stolen or modified mobile subagent, the static subagent can take different measures. As an example of measure, the static subagent can announce the hosts to do not accept the mobile subagent, and it may retransmit the mobile subagent with a different identity.

The ICMA agents' intelligence

In the literature there are described numerous intelligent static agents and intelligent multiagent systems composed from static agents [7, 8, 10, 20, 26, 27, 34, 35, 44, 45, 46].

Many times the agents capable to learn are considered intelligent [19, 42]. Learning allows to the agents to adapt for intelligent solving of the problems. There are few software mobile agents that can be considered intelligent [5, 4, 6]. Many times the multiagent system composed from cooperative mobile agents are considered intelligent [36, 39]. In these mobile multiagent systems, the intelligence is considered at the level of the system. If the mobile agents cooperate, they can solve intelligently problems.

Limitations in the endowment with intelligence of the mobile agents have practical reasons. The endowment of a mobile agent with intelligence increases the mobile agent body size and behavioral complexity. The transmission of a large number of intelligent mobile agents in a 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.

The intelligence of an *ICMA agent* is detained by the static subagent of the agent. A static subagent may have any sort of intelligence characteristic to the static agents, like: autonomous learning capability, capability to help other agents during their operation and cooperation capability. Applications of the *ICMA agents* for difficult medical problems solving prove practically their intelligence [52].

The static subagent of an ICMA mobile agent can be endowed with autonomous learning capability. It can learn new specializations and can improve its specializations. A mobile subagent may require the assistance of a static subagent during its operation. For example, we mention the situation when a mobile subagent does not have a specialization. In this situation, the mobile subagent may require the assistance of a static subagent, which has the necessary specialization, by transmitting the needed specialization.

Each static subagent may have a large number of specializations, which allows the autonomous solving of a large variety of heterogeneous problems. A static subagent can endow a created mobile subagent with any of its specializations. A static subagent can endow a mobile subagent with the necessary intelligence in operation.

ICMA agents can form cooperative multiagent systems called *ICMA multiagent systems* [16]. The motivations of this possibility consist in the ICMA mobile agents increased: intelligence, autonomy in operation, communication capability and security in operation. The intelligence of an *ICMA multiagent system* is higher than the intelligence of the member agents' intelligence.

4. Conclusions

Results described in the literature, prove that the intelligence of a system (agent or multiagent system) can offer advantages in the problems solving versus a system that does not have intelligence [7, 20, 26, 27, 34, 44]. Software mobile agents that can be used for many problems solving [11, 14, 52, 43, 47, 28, 29, 20, 49]. The development of intelligent software mobile agents represents an important open research direction. Many recently developed mobile agents described in the literature are endowed only with limited or even no intelligence [5, 4, 6]. Limitations in the endowment with intelligence of the mobile agents have practical reasons, which have been analyzed in this paper.

In our previous researches, a novel mobile agent architecture called *ICMA* was developed [16, 18]. Agents endowed with the *ICMA architecture* are called *ICMA agents*. The purpose of the study was the development of an intelligent mobile agent architecture, which allows the creation of mobile agents that can solve efficiently different problems. Advantages of the *ICMA agents* versus other mobile agents (like Tracy for example) consist in: increased security in operation [33] and increased communication capability [16, 30]. Other advantages of the *ICMA agents* consist in capability of problem allocation in large-scale networks [16]. ICMA agents can form cooperative multiagent systems [16]. The *ICMAE agents* [32, 23, 22] and *medical ICMA agents* [52] developed in our previous works, based on the *ICMA architecture*, proves that *ICMA agents* can be applied for problems solving using evolutionary problem solving techniques and specializations that allows medical diagnoses elaborations.

In this paper, we have analyzed the increased intelligence of the ICMA agents and the increased intelligence of the ICMA multiagent systems. There are analyzed the theoretical motivations that confirm the increased intelligence versus other realized mobile agents. The developed *medical ICMA agents* [52], used by a medical multiagent system for medical diagnosis problems solving, proves practically the intelligence of the ICMA agents. Practically a system's intelligence can be measured how well the system can solve problems (intelligence in the problems solving). The purpose of the endowment of an agent with intelligence, consist in the obtaining improvements in problems solving (solving of difficult problems, solving of problems whose description contain some uncertainties, solving problems whose solving is partially-known).

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