KNOWLEDGE-BASED MOBILE AGENTS

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Abstract. *In previous research, we have developed a novel mobile agent architecture called ICMA (Intelligent Cooperative Mobile Agent Architecture). The purpose of the study was to develop an architecture that allows the creation of intelligent mobile agents that can operate in insecure networks. In this paper, it is proposed a novel class of knowledge-based agents called knowledge based ICMA agents. The purpose of that study consists in the development of a novel class of mobile agents that can be endowed with knowledge bases. The mobile agents described in the literature can be endowed only with limited knowledge. The knowledge based ICMA agents are agents with the ICMA architecture endowed with knowledge bases. The knowledge-based ICMA agents combine the advantages of the knowledge based static agents and mobile agents in the problems solving. However, they can solve problems using efficiently the resources distributed in the network.*

Keywords: intelligent agent, multiagent system, complex system, agent architecture, mobile agent, knowledge-based agent, ICMA agent architecture

1. Introduction

The software 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. Mobile agent technology has been applied to develop solving methods for various kinds of parallel and distributed computing problems. The main disadvantages of the mobile agents consist in the limited intelligence, protection possibility against the malicious hosts and network sources and communication capability [13, 19, 11, 12, 9, 1, 30]. Another drawback of the mobile agents consists in the limited possibility of endowment with knowledge bases [4, 25, 3, 13].

The mobile agents are usually assumed to have only a very limited or even no intelligence [9, 11, 12]. The practical difficulties in the endowment of the mobile agents with intelligence are analyzed in [13; 19]. In many situations, the multiagent systems formed by cooperative mobile agents are considered intelligent [23, 26, 13]. The mobile agents' intelligence is considered at the level of multiagent system in which they operate.

The communication between mobile agents at different hosts is difficult [9, 13]. The mobile agents migrate during their operation from host to host. For this reason, it is difficult to establish where a mobile agent is at a moment in time.

The security solutions in mobile multiagent systems must include the protection of the hosts and the protection of the mobile agents [1, 29, 27, 15]. The main disadvantage of the mobile agents consists in their limited security in the network and against the hosts. The hardest disadvantage among all security issues raised by mobile agents consists in the protection of the agents against the hosts on which they are executing on. Once an 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 (code privacy), solutions for computing with secrets (data privacy) 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.

Some problems solving may require the use of knowledge bases. For example, we mention the medical diagnosis problems [22, 18, 20, 28]. The mobile agents are more limited in knowledge then the static agents. The mobile agents described in the literature have only limited knowledge [13, 4, 25, 3]. The limitations in knowledge of the mobile agents are related with the limited resources that they can use in the network and at the hosts. The endowment of a mobile agent with a knowledge base increases the mobile agent body size and his behavioral complexity. The transmission of a large number of knowledge based mobile agents in a network increases the overloading degree of the network. A large number of knowledge-based mobile agents at a host increases the overloading degree of the host. These reasons demonstrate the practical difficulties to use knowledge based mobile agents for problems solving.

The paper [22] introduces the notion *ubiquitous healthcare*, addressing the access of health services by individual consumers applying to mobile computing devices. This access requires knowledge about the individual health status, which may involve (as far as available) the current personal situation, relevant recent diseases, current symptoms or already available diagnosis. The required medical informations are extracted by the *OnkoNet* mobile agents, endowed with limited knowledge. They are specialized in patient-centric knowledge processing.

Different analyses related with mobile agents endowed with BDI architecture are realized in [4, 3]. The proposed BDI mobile agents can be endowed with limited knowledge.

The paper [25] analyzes the performance differences between static and mobile agents endowed with knowledge. The used agents are endowed with limited knowledge. They are specialized in information search.

2. Previous research

In our previous research, a novel mobile agent architecture called *ICMA* (*Intelligent Mobile Agent Architecture*) was developed [13, 19, 15]. The novelty of the proposed architecture consists in the combination of the static and mobile agents paradigms in the same agent architecture.

An agent denoted *Mag*, endowed with the *ICMA* architecture is composed from two parts (1) a static part *Ss* and a mobile part *Mp*.

$$Mag = \langle Ss \rangle + \langle Mp \rangle . \tag{1}$$

Ss is a static subagent. *Mp* is composed from a variable number of mobile subagents. *Ss* creates the mobile subagents at problem solving cycles. The mobile subagents operate as the mobile agents described in the literature they are responsible for the problems solving. *Ss* detains the knowledge bases of the mobile agent [13, 19]. The *ICMA* agents operation is described in [13, 19]. Different difficulties in the mobile agents' performance determination have been presented in [24, 5, 10]. For the *ICMA* mobile agents performance evaluation there have been realized simulations [13, 19]. The realized simulations show that an *ICMA* agent outperforms the performance of a traditional mobile agent in solving a large amount of problems.

The advantages of the developed *ICMA* agents consist in their increased communication capability [13], intelligence [13, 19] and protection possibility against malicious hosts and network sources [15]. These advantages are representative to most of the recently realized mobile agents, like *Tracy* [8, 6, 7, 2] and *OnkoNet* [22]. Other advantages of the *ICMA* agents consist in the capability to allocate problems for solving in large-scale networks [13].

The *ICMA* agents can be endowed with medical knowledge, this class of agents is called *medical ICMA agents* [20, 18]. The medical *ICMA* agents can be used for different medical problems solving. In the papers [20, 18] it is proposed a novel medical diagnosis multiagent system called *LMDS* (*Large Scale Medical Diagnosis System*) which uses medical *ICMA* agents as members. The medical *ICMA* agents can intelligently solve medical diagnosis problems. A mobile subagent of a medical *ICMA* agent can migrate in the network with an overtaken medical diagnosis problem, until will solve the problem cooperatively with other medical agents.

The *ICMAE* agents (*Intelligent Cooperative Mobile Agents with Evolutionary Problem Solving Capability*) represent a novel class of evolutionary agents developed during our previous research [21, 16, 14]. An *ICMAE* agent represent an agent with *ICMA* architecture endowed with evolutionary problem solving specializations. The *ICMAE* agents can solve problems whose solving require problem-solving methods based on evolutionary computation. The *ICMAE* agents eliminate the disadvantage of the evolutionary static agents related with the difficulty in the use of the resources distributed in the environment.

3. Knowledge-Based ICMA agents - A novel class of agents

The *ICMA* mobile agents presented in the previous section can be endowed with knowledge bases. We call this class of mobile agents *knowledge-based ICMA agents*. We denote with *Mag* a knowledge based *ICMA* agent. *Ss* represents the static subagent of *Mag*. *Ss* is endowed with a set $Sp=\{Sp_1, Sp_2,..., Sp_n\}$ of specializations that allow the solving of a set $Cl = \{Cl_1, Cl_2,..., Cl_n\}$ of classes of problems. The specializations Sp_1, Sp_2,..., Sp_n of the agent *Mag* are retained in a knowledge base denoted *kb*. Figure 2 illustrates a knowledge based *ICMA* agent. Ms_1, Ms_2,..., Ms_n represents the mobile subagents created by *Ss* at a problem solving cycle. *Pr* represent the problems transmitted for solving. The arrows used in the figure present the communication links between the subagents.

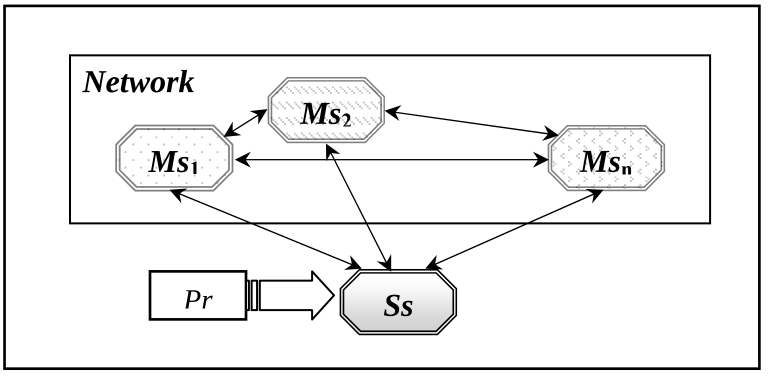

Figure 2: A knowledge based ICMA agent at a problem solving cycle

The algorithm *KnowledgeBasedICMAAgentOperation* describes briefly *Mag* operation at a Pr_h problem overtaking. Ms_i represents a mobile subagent created by *Ss* launched for problem solving in the network. A knowledge based *ICMA* agent may overtake a set of problems, that can be solved by the static subagent and one or more created mobile subagents. The algorithm presents a single problem solving.

Algorithm *KnowledgeBasedICMAAgentOperation*
{IN : Pr_h - the problem transmitted for solving}
{OUT : Sol_h - the solution of Pr_h}

@Step 1 - The problem overtaking for solving.

- *Ss* overtakes the informations known about the problem Pr_h.

@Step 2 - The problem initial processing.

If (*Ss* can processes Pr_h) *then*

@*Ss* processes Pr_h obtaining the result Rez_h.

Goto step *Step 5*.

else

@*Ss* creates Ms_i who is endowed with Pr_h and an itinerary *I*.

@*Ss* launches Ms_i to the first host specified in the itinerary *I*.

EndIf

@Step 3 - The problem solving.

While (the solution of the problem Pr_h is not obtained) *do*

@The current host *Hc* establishes depending on its the overloading degree if will execute Ms_i.

If (*Hc* can execute Ms_i) *then*

@*Hc* executes Ms_i obtaining the solution Sol_h.

Goto step Step 4

EndIf

If (the Ms_i itinerary *I* doesn't contain an unvisited host) *then*

@*Hc* introduces a new host in Ms_i itinerary *I*.

EndIf

@*Hc* transmits Ms_i to the next host specified in the itinerary *I*.

EndWhile

@Step 4 - The solution transmission to the static subagent.

- Ms_i transmits the solution Sol_h of the problem Pr_h to the static subagent *Ss*.

@Step 5 - The solution transmission to the problem sender.

- *Ss* transmits the solution Sol_h of the problem Pr_h to its sender.

EndKnowledgeBasedICMAOperation.

The *ICMA* agents' efficient communication capability in the paper [13] is analyzed. During their life cycle, the subagents of the same mobile agent can communicate. Mobile subagents at different hosts can communicate using as interloper their static subaget (the static subagent address is not changing during the mobile agent's life cycle). A mobile agent at a host can communicate with the static subagent even if the target mobile subagent migrates in the network during the transmission time. The communication between *ICMA* mobile agents is realized via their creator static subagents. Mobile subagents of different mobile agents use as interloper in the communication the static subagents who have created them. The communication capability of the subagents allows the cooperation during the problems solving. A mobile may require knowledge from static subagents during its operation. A mobile subagent at a host lives the knowledge that is not necessary in the following. However, the knowledge quantity detained by a mobile subagent decrease in time during the mobile agent's life cycle.

4. Conclusions

During our previous research, we have developed a novel intelligent agent architecture, called *ICMA* (*Intelligent Cooperative Mobile Agent Architecture*) [13, 19, 15]. The purpose of this research was to create an intelligent mobile agent architecture, which allows the creation of mobile agents that can intelligently solve problems operating in insecure networks. An application of the *ICMA* agents is presented in [20, 18]. In the papers [21, 16, 14] *ICMA* agents endowed with evolutionary problem solving specialization are presented.

Developed mobile agents described in the literature can be endowed only with limited knowledge [13, 4, 25, 3]. The purpose of the research described in this paper is to develop a novel class of mobile agents that can be endowed with knowledge bases. It is proposed a novel class of mobile agents called knowledge based *ICMA* agents. The advantage of a knowledge based *ICMA* agents consists in the problem solving using efficiently the resources of the computing system where he operate and the resources distributed in the network. A static subagent of a knowledge based *ICMA* agent can use the resources of the computing system on which he operate. A static subagent solves problems as a knowledge-based agent. The knowledge base of an agent is detained by its static agent. If the static subagent is overloaded, he can create mobile subagents that can solve problems at hosts. The mobile subagents launched for problem solving uses the resources of the hosts. A static subagent based on the overtaken problems at a problem solving cycle and the detained knowledge, create the mobile subagents, which will be endowed only with the necessary knowledge in the problem solving. However, they do not overload the network with data transmission and the hosts with data processing. The main advantage of the proposed knowledge based *ICMA* agents versus the static knowledge based agents consists in the flexible use of the resources distributed in the environment.

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