KNOWLEDGE-BASED MOBILE AGENTS

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Abstract. In previous researches, a novel mobile agent architecture called *ICMA* (*Intelligent Cooperative Mobile Agent Architecture*), which represents a combination of the mobile and static agents paradigms have been proposed. The purpose of the study was to develop an architecture, which allows the creation of intelligent mobile agents that can operate in insecure networks. In this paper a novel class of knowledge-based agents called *KICMA* (*Knowledge-based ICMA Agents*) is proposed. The purpose of the study, consists in the development of a novel class of mobile agents based on the *ICMA* architecture, which can be endowed with large knowledge bases. Recently developed mobile agents, described in the literature can be endowed only with limited knowledge. The *KICMA* 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 detained knowledge and the problem solving resources distributed in the network.

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1. Introduction

Some agents are cognitive systems used for problems solving in many domains [33, 17, 18, 20, 30]. As examples of applications of cooperative agents we mention the medical domain. Applications of the agents for fulfilling medical tasks includes: *patients monitoring*[37], *patients management* [38, 39], *healthcare*[40], *telehealth* [41], *analysis of spread simulation of infectious disease*[42], *web-enabled healthcare computing* [43] and *ubiquitous healthcare* [22].

A class of agents is represented by the *software mobile agents* [9, 5, 11, 23]. 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.

Mobile agents are computational software processes capable of roaming wide area networks such as WWW, interacting with foreign hosts, gathering information on behalf of their users and coming back having performed the problems (tasks) solving duties set by their users [34]. Each host offers different services to the mobile agents. The problems solving methods are described in the mobile agents' body. A mobile agent body is composed from a software code and different data. The code describes the overtaken problems solving. The data are used during the overtaken problems solving. A specialization represents the method that describes the solving of a class of problems. A mobile agent at a host in collaboration with the host solves the problems. The host executes the specifications described in the mobile agent body. A mobile agent may interrupt a problem solving at a host. The solving of an interrupted problem must be continued at another host. In such situations, the mobile agent body must contain the state of the interrupted problem solving. The main advantage of the mobile agents is the low data transmission in the network where they operate. As examples of applications of the mobile agents, we mention [35]: the fields of manufacturing planning, Internet traffic management, Internet search and ubiquitous healthcare.

As examples of realized mobile agents, we mention: *Tracy* and *OnkoNet*. *Tracy* agents have been developed at Friedrich Schiller University [2, 7, 8]. The main advantage of the *Tracy* agents consists in their capability to optimize the migration in the network.

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, that 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, specialized in patient-centric knowledge processing.

In Section 2 there are analyzed different aspects related with the mobile agents. Section 2.1 presents some disadvantages of the mobile agent that limit their applicability for some problems solving. Section 2.3 presents motivations that confirm the difficulties related with the endowment of the mobile agents with knowledge bases.

Section 3 presents previous researches related with the mobile agents. There are presented the *ICMA* (*Intelligent Cooperative Mobile Agent Architecture*) mobile agents.

In Section 4 a novel class of knowledge-based mobile agents called *KICMA* (*Knowledge-based ICMA Agents*) is proposed.

Section 5 presents the conclusions of the paper.

2. Mobile agents

2.1. Disadvantages of the Mobile agents

The main disadvantages (that arise due to the migration of the mobile agents in the network) of the mobile agents described in the literature, consists in the limited [1, 9, 11, 12, 13, 19]: intelligence, protection possibility against the malicious hosts and network sources and communication capability. Another drawback of the mobile agents consists in the limited possibility to be endowed with knowledge bases [3, 4, 13, 24, 26, 27, 29].

The communication between mobile agents at different hosts is difficult [9, 13]. Mobile agents migrate during their operation from host to host. Is difficult to establish where a mobile agent is at a moment of time. In the case of a mobile agent launched in the network for problems solving, cannot be established precisely the migration time and the execution time at the hosts.

The mobile agents are usually assumed to have only a very limited or even no intelligence [9, 11, 12]. 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 [13, 23]. The mobile agents' intelligence is considered at the level of the multiagent system in which they operate. If the mobile agents cooperate efficiently, they can solve intelligently difficult problems.

The security solutions in mobile multiagent systems must include the protection of the hosts and the protection of the mobile agents [1, 15, 28, 31, 32]. 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. 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.

2.2 Knowledge-based mobile agents

Some difficult problems solving by agents may require the use of knowledge detained in knowledge bases. For example, we mention the medical diagnosis problems, whose solving require medical diagnosing knowledge [17, 18, 22, 30]. Mobile agents are more limited in knowledge then the static agents. The mobile agents described in the literature have only limited knowledge [3, 4, 13, 24, 26, 27, 29]. Different analyses related with mobile agents endowed with *BDI architecture*, endowed with limited knowledge, are realized in [3, 4]. The paper [26] analyzes the performance differences between static and mobile agents, endowed with limited knowledge, specialized in information search.

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 related with the communication (the knowledge based agent must be transmitted in the network). A large number of knowledge-based mobile agents at a host increases the overloading degree of the host related with the processing. These reasons demonstrate the practical difficulties to use knowledge-based mobile agents for difficult problems solving.

The paper [29] presents a mobile agent platform called *SyMPA*, that supports both static and mobile agents implemented using the high-level agent-oriented programming language *CLAIM*. Mobile agents designed using *CLAIM*, are endowed with cognitive capabilities, they are able to communicate with other agents. The primitives of mobility are inspired from the *ambient calculus*. The paper [29] is focused on *SyMPA*'s architecture, mobility, implementation and security elements.

3. Previous work

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 [36]. In our previous researches, a novel mobile agent architecture called *ICMA* (*Intelligent Mobile Agent Architecture*) was developed [13, 15, 19]. The novelty of the proposed architecture consists in the combination of the static and mobile agent paradigms in the same agent architecture. An agent endowed with the *ICMA* architecture, is composed from two parts: a static part *Sa* (*Sa* is a static subagent) and a mobile part *Mp*= $\{Ms_1, Ms_2, \dots\}$. *Ma* is composed from a variable number of mobile subagents. *Sa* creates the mobile subagents $Ms_1, Ms_2, \dots$ at problem solving cycles. The *ICMA* mobile subagents operate as the mobile agents described in the literature, they are responsible for the overtaken problems solving. The *ICMA* agents operation is described in [13, 19]. Different difficulties in the mobile agents' performance determination have been analyzed in [5, 10, 25]. For the *ICMA* agents performance evaluation, there have been realized simulations using a developed simulation environment [13, 19]. The realized simulations show, that an *ICMA* agent outperforms the performance of a traditional mobile agent in solving large amounts of problems.

The advantages of the *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 implemented mobile agents, like *Tracy* [2, 6, 7, 8] developed at Friedrich Schiller University of Jena. Another advantage of the *ICMA* agents, consist in their 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* [18, 19]. The medical *ICMA* agents can be used for different medical problems solving. In the papers [18, 19], a novel medical diagnosis multiagent system called *LMDS* (*Large Scale Medical Diagnosis System*), which uses medical *ICMA* agents as members is proposed. Medical *ICMA* agents can solve intelligently 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 agents developed during our previous researches [14, 16, 21]. An *ICMAE* agent is 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 operation is the same with the *ICMA* agents operation, the only difference consists in the specializations used at the hosts (*ICMAE* agents use evolutionary problem solving methods). *ICMAE* agents eliminate the disadvantage of the evolutionary static agents, related with the difficulty in the use of the resources distributed in the network.

4. Knowledge-Based ICMA agents

In the following, we propose the endowment of the agents with the *ICMA* architecture, presented in the previous section with knowledge bases. We call this novel class of agents *KICMA* (*Knowledge-based ICMA Agents*). Figure 1 presents a *KICMA* agent at a problems solving cycle. A problems solving cycle begins at the overtaking of a set of problems and is finished when all the overtaken problems are solved. We denote *KBMA* a *KICMA* agent. *KMBA* agent is composed from two parts (1): a static part denoted *Sa* and a mobile part denoted *Mp*= $\{Ms_1, Ms_2, \ldots\}$.

$$KBMA = < Sa > + < \{Ms_1, Ms_2, \ldots\} > . \tag{1}$$

Sa represents the static subagent of *KBMA*. *Sa* is endowed with a set *Spec*(*KMBA*) (2) of specializations, which allow the solving of a set $C = \{C_1, C_2, \ldots, C_k\}$ of classes of problems. The specializations $S_1, S_2, \ldots, S_k$ of the agent *KBMA* are retained in a knowledge base denoted *Kb*= $\{S_1, S_2, \ldots, S_k\}$.

$$\begin{array}{l} Spec(KBMA) = [S_1; S_2; \ldots; S_k] \\ \forall j = \overline{1,k} \qquad < S_j > \rightarrow < C_j > \end{array} \tag{2}$$

In Figure 1 are used the following notations: $Ms_1, Ms_2, \ldots, Ms_r$ represent the mobile subagents created by the static subagent *Sa* at a problems solving cycle; $P_1, P_2, \ldots, P_x$ represent the problems transmitted for solving at the problems solving cycle. The arrows between the subagents of the agent, used in Figure 1 present the communication and cooperation links between the subagents.

The algorithm *KICMAOperation* describes briefly the *KMBA* agent operation at a problem denoted P_h overtaking. The algorithm *KICMAOperation*

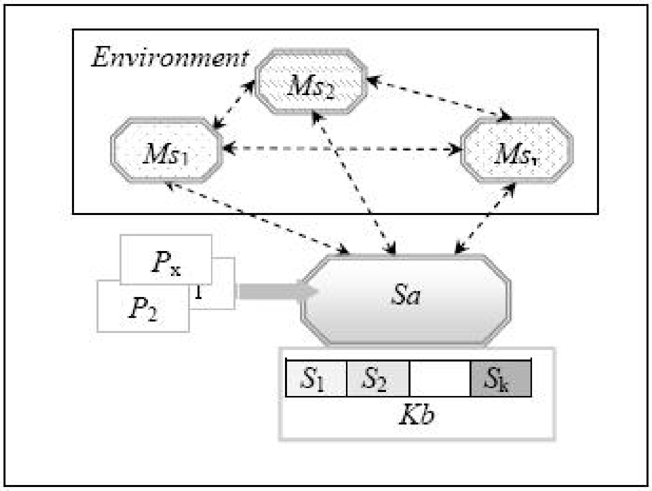

Figure 1: A KICMA agent

presents the simplified case, when is overtaken for solving a single problem. Ms_i ($Ms_i \in Mp$) is a mobile subagent created by *Sa* launched for the P_h problem solving in the network. *KMBA* may overtake a set of problems, that can be solved by the static subagent and/or one or more created mobile subagents. *Kb*= $\{S_1, S_2, \ldots, S_k\}$ represents the *KMBA* knowledge base detained by *Sa*. $H = \{H_1, H_2, \ldots, H_d\}$ represents the set of hosts distributed in the network.

Algorithm KICMAOperation

{IN : P_h - the problem transmitted for solving}

{OUT : SL_h - the solution of P_h}

Step 1 - The problem overtaking for solving.

@*Sa* overtakes the P_h problem description.

Step 2 - The problem initial processing.

If (*Sa* can solve P_h) *then*

@*Sa* using the knowledge contained in *Kb* solve P_h obtaining SL_h.

Goto Step 5.

else

@Sa creates Ms_i who is endowed with an itinerary I_S and the knowledge necessary in P_h solving.

@Sa launches Ms_i to the first host specified in the itinerary I_S.

EndIf

Step 3 - The problem solving.

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

@The current host H_c ($H_c \in H$) establishes depending on its overloading degree if will execute Ms_i.

If (H_c can execute Ms_i) *then*

@H_c executes Ms_i obtaining the solution SL_h.

Goto Step 4.

Endif

If ($I_S \neq \emptyset$) *then*

$I_S = I_S \cup \{H_u\}$ (H_c introduces a new host H_u in the itinerary I_S).

EndIf

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

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

EndWhile

Step 4 - The solution transmission to the static subagent.

@Ms_i transmits the solution SL_h of the problem P_h to the static subagent Sa.

Step 5 - The solution transmission to the problem sender.

@Sa transmits the solution SL_h of the problem P_h to its sender.

EndKICMAOperation.

Figure 2 presents how a *KICMA* agent, uses the detained knowledge, at a problem solving cycle (solving of the set $P = \{P_1, P_2, \ldots, P_e\}$ of problems). Sa represents the static subagent of the knowledge-based agent. Sa can uses the detained knowledge base Kb. $Ms_1, Ms_2, \ldots, Ms_r$ represents the created mobile subagents by Sa, that uses knowledge from Kb (each agent uses some of the knowledge). Ms_1 uses the knowledge S_x ($S_x \subseteq Kb$); Ms_2 uses the knowledge S_y ($S_y \subseteq Kb$); Ms_r uses the knowledge S_z ($S_z \subseteq Kb$) ; where $S_x \cup S_y \cup S_z \subseteq Kb$.

The communication capability of a *KICMA* agent is the same with an *ICMA* agent's communication capability. The *ICMA* agents' efficient communication capability is analyzed in [13]. We denote with Ki_1 a *KICMA* agent. We denote with Ss_1 the static subagent of Ki_1. We denote Mp= $\{Ms_1, Ms_2, \ldots\}$ the mobile subagents of Ki_1 distributed in the network. During their life cycle the subagents $Ms_1, Ms_2, \ldots, Ms_b$ and Ss_1 can communicate. Ss_1 address is not changing during Ki_1's life cycle. A mobile subagent Ms_a ($Ms_a \in Mp$) announces Ss_1 when he arrive at a host H_b and when he lives the host H_b, however Ss_1 can communicate with Ms_a.

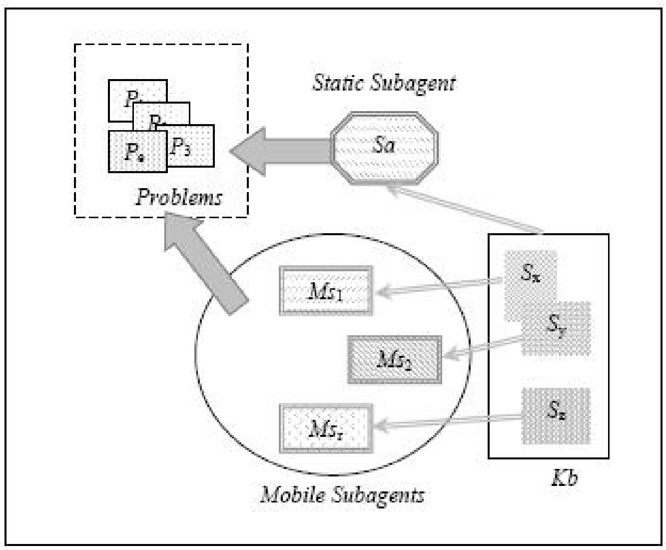

Figure 2: The knowledge used by a knowledge-based ICMA agent

KICMA agents can form multiagent systems. One of the main proprieties necessary for the agents to form multiagent systems consists in the communication capability. The agents must be able to communicate with each other. We denote $MAS = \{Ki_1, Ki_2, \ldots, Ki_c\}$ a multiagent system composed from *KICMA* agents.

Let Ki_v ($Ki_v \in MAS$) and Ki_z ($Ki_z \in MAS$) two *KICMA* agents. We denote with Ss_v the static subagent of Ki_v. We denote with Ss_z the static subagent of Ki_z. Ss_v and Ss_z can communicate directly (their address is not changing during their life cycle). Mobile subagents of Ki_v and Ki_z at the same host can communicate directly.

Two mobile subagents denoted Ms_q (Ms_q mobile subagent of Ki_v) and Ms_w (Ms_w mobile subagent of Ki_z) at different hosts communicate using as interloper their creator static subagents Ss_v and Ss_z. We consider the situation when Ms_q wants to transmit a message denoted mi to Ms_w. Ms_q transmits mi to Ss_v. Ss_v will forward mi to Ss_z. Ss_z will send mi to Ms_w when Ms_w operate at a host.

A mobile subagent at a host, can communicate with a target mobile subagent at another host even if, the target mobile subagent migrates in the network during the transmission time (the static subagent transmits the data to the target mobile agent when this one has arrived at a host). The communication capability of the subagents allows the cooperation during the problems solving. A mobile subagent 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 operation. However, the knowledge quantity detained by a mobile subagent decreases in time during the mobile subagent's life cycle. Is not necessary for a mobile subagents to return at the creator static subagent. The obtained problem solutions are sent to the static subagent when they are obtained. A static subagent creates the mobile subagents at the beginning of each problems solving cycle.

5. Conclusions

In our previous researches, a novel intelligent mobile agent architecture called *ICMA* (*Intelligent Cooperative Mobile Agent Architecture*) was developed [13, 15, 19]. Mobile agents based on the proposed architecture can solve intelligently problems. An application of the *ICMA* agents for medical diagnosis problems solving is presented in [18, 19]. In the papers [14, 16, 21] *ICMA* agents endowed with evolutionary problem solving specializations called *ICMAE agents* (*Intelligent Cooperative Mobile Agents with Evolutionary Problem Solving Capability*) are presented.

Recently developed mobile agents can be endowed only with few knowledge which limit their applicability for difficult problems solving [3, 4, 13, 26]. The purpose of the study described in this paper, consists in the development of a novel class of mobile agents, that can be endowed with knowledge bases. Is proposed a novel class of knowledge-based agents called *KICMA* (*Knowledge-based ICMA Agents*). The main advantage of the proposed *KICMA* agents versus the static knowledge-based agents, consists in the efficient use of the resources distributed in the network. A static subagent of a *KICMA* agent can use the resources of the computational system on which he operate. An *ICMA* static subagent solve problems as a knowledge-based static agent (the knowledge base of a proposed agent is detained by its static agent). If the static subagent is overloaded, he can create mobile subagents that can solve problems at hosts distributed in the network. The mobile subagents launched for problem solving uses the resources of the hosts during the problems solving. A static subagent based on the overtaken problems at a problem solving cycle and the detained knowledge base 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.

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