University of Piteşti
Faculty of Mathematics and Computer Science

MOBILE AGENTS MODELING AND THEIR USE TO KNOWLEDGE REPRESENTATION AND PROCESSING

-Summary of the PhD Thesis-

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KEY-WORDS: Software agent, mobile agent, multi-agent system, knowledge representation, knowledge processing, knowledge bases, inheritance, factorization, interrogation, decidability problem, inheritance knowledge base, knowledge management, master/slave system, Java.

1. Introduction. Thesis objectives

Developing multi-agent systems and knowledge representation and processing are important issues in research areas such as artificial intelligence, complex systems management or distributed calculation. Simulations based on agents are close to natural processes and they ensure superior results to those provided by classical models, such as differential equations systems. Some researchers believe agents a new paradigm of computational research area.

This thesis presents theoretical and practical elements regarding the development of a multi-agent system, in order to represent and process knowledge bases. The system is presented by

describing the structure and computational process, accompanied by the mathematical justification of the proposed model and also using the developed system in real world problems with experimental results analysis and conclusive remarks.

The research proposed in this PhD thesis can be placed in a common area of the mathematics and informatics. First, in this thesis it is integrated the concept of mobile agent in an algebraic environment of knowledge representation and processing, which is obtained using some concepts of universal algebra. In this paper work is studied the mathematical formalism for knowledge representation and processing using the inheritance concept and the result of this approach is materialized in a proper view on the formal description of the multi-agent systems. This approach will lead to a simple and concise theory with applications in various areas: transportation, medicines, Internet, economics, e-learning, etc. That explains the connection with the mathematical field. In terms of informatics, here are distinguished several areas of research from the PhD thesis that are closely related: defining a model of multi-agent system - which involves important notions of artificial intelligence, programming mobile agents - which is a relatively new field in computer science, the implementation of mobile agents using the latest software technology (Java 2 Standard Edition, Java 2 Enterprise Edition, Aglets, Middleware Applications / Server: Java Servlets).

The main objectives of this thesis can be described as follows:

1. Approaching theoretical issues in the vision of mobile agents usage for knowledge processing, represented by the following methods:
   - knowledge representation using the inheritance concept;
   - numerical knowledge representation for 3D surfaces deformation modeling;
   - representation based on type of semantic schemas.
2. Designing the structure of a mobile agents system able to process knowledge, particularly those listed above.
3. The architecture of the proposed mobile agents system and the study of its efficient usage are presented.

The main results established in this thesis were publicized in the proceedings of several conference or journals, most of them indexed in the Thomson ISI database, in the list of ISI indexed Proceedings.

2. Multi-agent system for knowledge processing. Original contributions

In this chapter of the thesis it is developed a mobile agents based system which has to represent and process knowledge. A mobile agent is defined as a software program that can be dispatched from one computer to another, in order to action and interact with another agent. They are not fixed where the system has started to run the program, but can move on different machines in the network. Thus, the system becomes very flexible because the calculations can be made on any machine, through the agents, which can move in order to obtain the resources and values necessary for completing the tasks. In this way, we define the multi-agent system for knowledge representation and processing as a tuple MAKPS=(R, AP, $\{S_i\}_{i=1}^n$, $\{C_j\}_{j=1}^m$, $\{KB_i\}_{i=1}^n$, L), where:

- R represents the Root server;
- AP represents the Agents Package;
- $\{S_i\}_{i=1}^{n}$ represents the set of all servers from the system;
- $\{C_j\}_{j=1}^{m}$ represents the set of all clients from the system;
- $\{KB_i\}_{i=1}^{n}$ represents the knowledge bases from the servers, which are components of the general knowledge base KB;
- L represents the communication language from the system.

The structure of the multi-agent system can be visualized in the Figure 1.

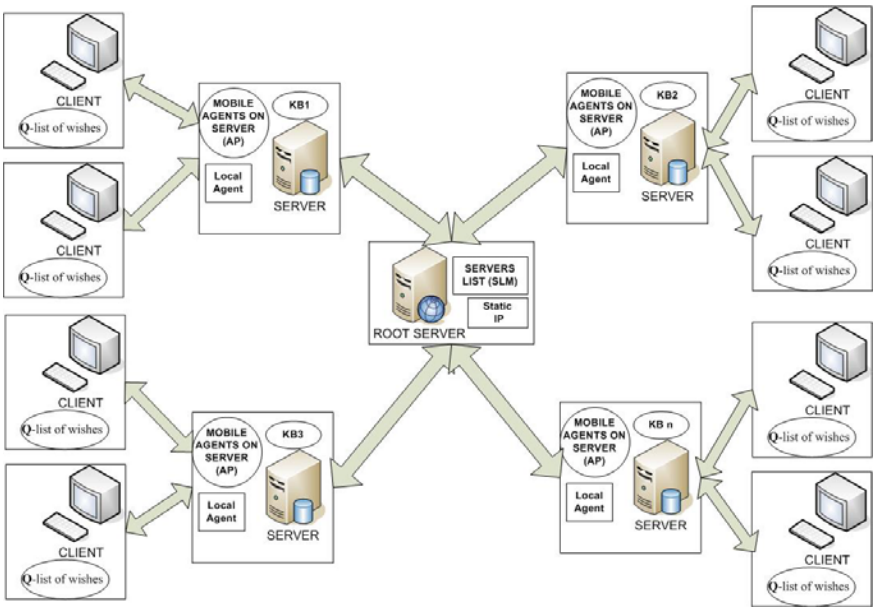

Figure 1: MAKPS system structure

The system is able to process the knowledge bases distributed on its servers. For this purpose, there are Querry Mobile-Agents (QMA) that are visiting one at a time, all or parts of these servers from whom they require a certain information, that corresponds to the user requirements for whom they work. When an agent totally accumulates the answers for the user's interrogations, it returns and transmit the results.

To enable communication in the MAKPS is used the Agent Transfer Protocol (ATP), which is an application-level protocol for transmission of mobile agents. ATP offers the opportunity to handle agent mobility in a general and uniform way and supports message-passing, based on a *request/response* paradigm between agent services.

The proposed system indicates a model for processing knowledge bases in a master/slave environment. Without a doubt the obtained results improve the problem of knowledge bases representation and processing using agents.

These results are reported in the following work papers:
1. C.I. Popîrlan, M. Florescu, Mobile Agents System for Knowledge Bases Processing, Proceedings of the 8^{th} International Conference on Artificial Intelligence and Digital Communications - AIDC 2008, Craiova, Romania, volume 108, pages. 148-156, Reprograph Press, ISBN 978-973-671-161-9, 2008.
2. C.I. Popîrlan, Knowledge Bases Modeling using Mobile Agents, INFORMATICA International Journal, ISSN 0868-4952, submitted, 2008.

3. Multi-agent system based on inheritance. Original contributions

Following the performed research in the mathematical context of multi-agent system for knowledge representation and processing, are presented the following results:

- It is proposed a model of knowledge representation based on the inheritance mechanism, named *inheritance knowledge base*. An *inheritance knowledge base* is a pair $K = (Obj(K), \rho_K)$, where:

  1. $Obj(K) \subseteq L_{obj} \times 2^{L_{obj}} \times 2^{L_{attr} \times (V_{dir} \cup L_{proc}) \times Param}$ is a finite set of elements named the **objects** of K, such that if $x = (N(x), P_1, Q_1) \in Obj(K)$, $y = (N(y), P_2, Q_2) \in Obj(K)$ and $N(x) = N(y)$ then $P_1 = P_2$ and $Q_1 = Q_2$.
  2. $\rho_K \subseteq Obj(K) \times Obj(K)$ is the relation generated by K, which is defined as follows:

  $$(x, y) \in \rho_K \Longleftrightarrow N(x) \in P_y$$

  3. $\rho_K^i \cap \rho_K^j = \emptyset$ for $i \neq j$

- It is defined the response function Val_{attr} and its mathematical properties are studied (calculability). We define the mapping

  $$Val_{attr} : Obj(K) \times Attr(K) \longrightarrow (V_{dir} \times Param) \cup \{unknown, error\}$$

  as follows:

  - If $h(x, a_1) = (v_1, q_1)$ and $v_1 \in V_{dir}$ then $Val_{attr}(x, a_1) = (v_1, q_1)$.
  - If $h(x, a_1) = (p_1, q_1)$ and $p_1 \in Proc(K)$ then we consider the following two cases:
    1. If $Arg(p_1) = (b_1, \ldots, b_r)$ and $Val_{attr}(x, b_1) = (v_1, q_1)$, ..., $Val_{attr}(x, b_r) = (v_r, q_r)$ are elements of $V_{dir} \times Param$ then $Val_{attr}(x, a_1) = (u, q)$, where $p_1(Val_{attr}(x, b_1), \ldots, Val_{attr}(x, b_r)) = (u, s)$ and $q = adj(q_1, s)$.
    2. Otherwise $Val_{attr}(x, a_1) = error$.
  - If $h(x, a_1) = no$ then $Val_{attr}(x, a_1) = unknown$.

  Because this function is a recursive one, the main issue is to calculate the values of Val_{attr} function in a finite number of steps for any pair $(object, attribute)$. It is studied this problem, and is demonstrate a necessary and sufficient condition for the $Val_{attr}(object, attribute)$ value to be calculated in limited steps. Based on this condition, the problem of stopping the response function calculus is a problem of decidability.

- It is studied the problem of the *inheritance knowledge base* decomposition into its components and this subject is named *the factorization of a knowledge base*. It is defined a calculus method for knowledge base components, which demonstrates that the components are generated by the *initial objects* (objects without parents).

  We consider an accepted knowledge base K and we recall that the inheritance relation generated by K is $inh_K = \bigcup_{p\geq 1} \rho_K^p$. The relation inh_K, generated by an inheritance knowledge base, allows to compute these parents because the parents of $x \in Obj(K)$ is the set $\{y \in Obj(K) \mid (y, x) \in inh_K\}$.

  We consider the space $(Initial(K), \sigma_K)$, where σ_K is the restriction of $\widetilde{\rho}_K$: for every $x, y \in Initial(K)$ we have $(x, y) \in \sigma_K$ if and only if $(x, y) \in \widetilde{\rho}_K$. The binary relation σ_K is an equivalence relation on $Initial(K)$ because $\widetilde{\rho}_K$ is an equivalence relation on $Obj(K)$. We can consider the factor set $Initial(K)/\sigma_K$. It is demonstrated that: T is a component of K if and only if $T \in Obj(K)/\widetilde{\rho}_K$.

  As a result of this process several components of the *inheritance knowledge base* are obtained.

  These results are reported in the following work papers:
  1. C.I Popîrlan, N. Ţăndăreanu, An Extension of Inheritance Knowledge Bases and Computational Properties of their Answer Functions, Annals of University of Craiova, Mathematics and Computer Science Series, ISSN 1223-6934, volume 35, pages 155-176, 2008.
  2. C.I. Popîrlan, N. Ţăndăreanu, Factorization of an Inheritance Knowledge Base, Knowledge and Information Systems, ISSN 0219-1377, submitted, 2008.

- It is defined a multi-agent system using the demonstrated mathematical model. A master-slave system configuration is used. The system is defined as a structure $MASI = (M_a, \{S_i\}_{i=1}^n, \{QM_i\}_{i=1}^n, \{KB_i\}_{i=1}^n, L)$, where:

  - M_a represents the master agent;
  - $\{S_i\}_{i=1}^n$ represents the set of all slave agents;
  - $\{QM_i\}_{i=1}^n$ represents the set of all questions for mobile agents (interrogations);
  - $\{KB_i\}_{i=1}^n$ represents the *inheritance knowledge base* components;
  - L represents the communication language.

  This system includes a master agent and a set of slave agents. Each component of the *inheritance knowledge base* can be saved on a station from the network, and the knowledge processing for one component is done by a slave agent. Thus, if the knowledge base can be decomposed into n components, then n slave agents are used in the system.

4. Knowledge modeling using MAKPS system. Original contributions

In the context of using the proposed multi-agent system in the real world problems with experimental results analysis are discussed several aspects. There are presented two usage cases for initial different configurations of the multi-agent system:

- Knowledge processing represented by a tree level structure (which is commonly used in knowledge modeling for complex mechanisms assembling). This case describes some experiments for the situation of two agents engaged together in assembling a bicycle from its parts scattered inside a garage. It is proposed an optimization algorithm for mobile agents transfer through the network;

- Numerical knowledge representation for 3D surfaces deformation modeling. This case describe some experiments for a 3D elastic model (sailing ship), represented with particles connected with elastic springs. The multi-agent system is used to extract the forces information (internal and external forces) and to change the elastic properties of the model, for a better representation and visualization.

These results are reported in the following work papers:
1. C.I. Popîrlan, C. Popîrlan, Algorithms for Mobile Agents in Network using Tracy (Mobile Agent Toolkit), Proceedings of the 5^{th} RoEduNet IEEE International Conference, 1-3 June, Sibiu, Romania, pages 337-340, ISBN (10) 973-739-277-9, ISBN (13) 978-973-739-277-9, 2006.
2. C.I. Popîrlan, C. Popîrlan, Mobile Agents communication for knowledge representation, Proceedings of the 11^{th} World Multi-Conference on Systemics, Cybernetics and Informatics (WMSCI 2007), July 8-11, Orlando, Florida, USA, volume I, pages 92-96, IIIC Press, ISBN (10) 1-934272-15-9, ISBN (13) 978-1-934272-15-2, 2007.
3. C.I. Popîrlan, M. Dupac, A Mobile Agents approach for 3D elastic medium modeling and visualization, Annals of University of Craiova, Mathematics and Computer Science Series, ISSN 1223-6934, volume 34, pages 115-123, 2007.
4. C.I. Popîrlan, M. Dupac, A Web-visualization approach for 3D elastic medium modeling and simulation, Proceedings of the 19^{th} IASTED International Conference on Modelling and Simulation (MS 2008), May 26-28, Quebec City, Quebec, Canada, pages 224-230, ACTA Press, ISBN 978-0-88986-741-3, 2008.
5. C.I. Popîrlan, M. Dupac, A web-base approach for 3D mechanism components modeling and visualization, Proceedings of the 17^{th} IASTED International Conference on Applied Simulation and Modelling (ASM 2008), June 23-25, Corfu, Greece, pages 123-129, ACTA Press, ISBN 978-0-88986-748-2, 2008.

5. MAKPS system architecture. Implementation aspects. Original contributions

In this chapter is presented an implementation of the multi-agent system for knowledge processing (MAKPS), described in previous chapters, with support provided by the Java programming language and Aglets development package from the IBM company. Thus is created a toolkit, named MAKPT (Mobile Agents Knowledge Processing Toolkit), which uses mobile agents to process knowledge bases. This toolkit is described from the implementation's perspective and there are presented three examples of MAKPT testing:

1. In the air transport area (processing information of flights): the knowledge base (Figure 2 is structured on five levels: Level 1 - information about class comfort, Level 2 - information about the people who are in traffic, Level 3 - information about the flights, Level 4 - the name of departure flights airport, Level 5 - the name of arriving flights airport.

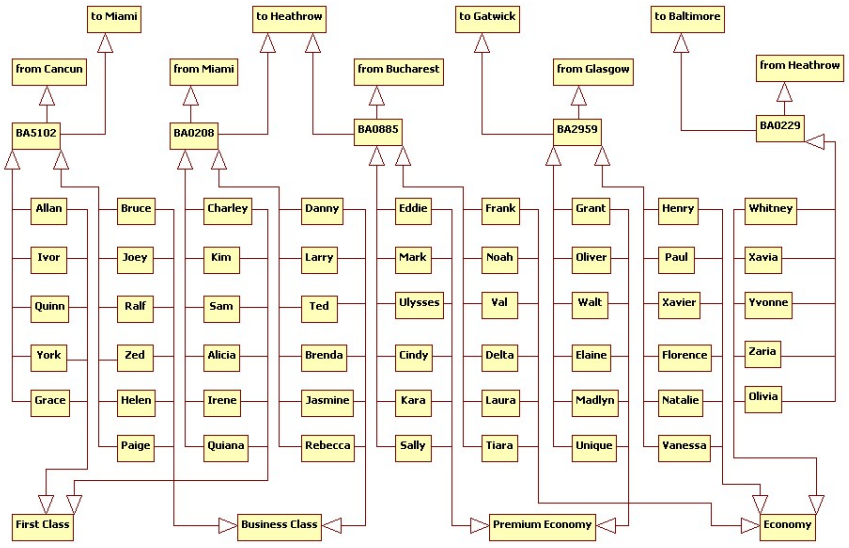

Figure 2: The structure of the knowledge base for the air transport

For this test the results of an interrogation are displayed in 2.2 seconds.

2. In the medicine area (diagnosing diseases): the knowledge base is structured as follows:

   - Level 1: initial knowledge: symptoms;
   - Level 2: extensive knowledge: diseases;
   - Level 3: primary knowledge: treatments.

   The average of the running times was 2 seconds per test. In that time a mobile agent visited each server (once or several times) and then returned the results.

3. In the police field (the establishment of drug dealer location): we considered a scenario that uses a knowledge base structured on three levels: Level 1 - drug dealers; Level 2 - cities; Level 3 - countries. The knowledge base (Figure 3) includes 29 entities (13 drug dealers, 11 cities and 5 countries) distributed randomly on 10 servers.

   Each server runs on the same type of computer (1600 MHz processor, 2 GB RAM), but having a different port number. The running time average was 3 seconds per test. In this time a mobile agent visits each server (once or several times) and then returned to the starting point with the results.

This research are reported in the following work papers:

1. C.I. Popîrlan, M. Florescu, Mobile Agents System for Knowledge Bases Processing, Proceedings of the 8th International Conference on Artificial Intelligence and Digital Communications - AIDC 2008, Craiova, Romania, Reprograph Press, Vol.108, pp. 148-156, ISBN 978-973-671-161-9, 2008.

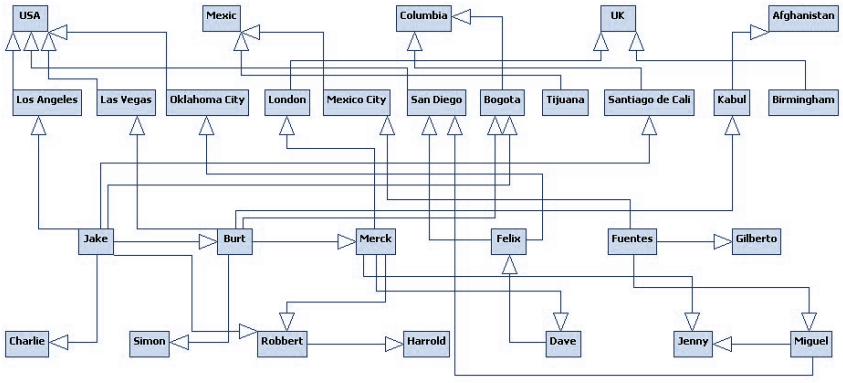

Figure 3: The structure of the knowledge base for the Police

2. C.I. Popîrlan, MAKPT: Mobile Agents Toolkit for Knowledge Processing, Journal of Artificial Intelligence Review, ISSN 0269-2821, submitted, 2008.
3. C.I. Popîrlan, Knowledge Bases Modeling using Mobile Agents, INFORMATICA International Journal, ISSN 0868-4952, submitted, 2008.

6. Conclusion and future work

The PhD thesis focuses on the research in the field of multi-agent systems, mainly on modeling and application of mobile agents in knowledge representation and processing. In this way three major aspects are presented:

1. Development of a new technique for knowledge representation based on the inheritance concept in order to use the mobile agents for knowledge processing;

2. Development of a multi-agent system based on a master/slave configuration of agents which uses the proposed technique;

3. The applicability of the multi-agent system in the real world problems.

The obtained results are mathematically based and experimentally demonstrated, representing the original contribution in developing the proposed multi-agent system and using it in the real world problems. As future objectives we lay down:

- Extending the model of proposed multi-agent system by implementing distributed calculus;

- Using the system proposed in the e-learning and sales force automation;

- Improving the computational aspects of the system by optimizing the implementation for mobile agents.