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Functional structure of reflexive-active systems of artificial heterogeneous intelligent agents

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Abstract. The paper is aimed at developing distributed artificial intelligence systems for relevant simulation of collective solving of practical problems by modeling reflection. The paper presents the basic design principles and typical functional structure of reflexive-active systems of artificial heterogeneous intelligent agents. Agents of such systems mutually model each other’s reflexive positions; dynamically develop tactics and strategies for their behavior that are relevant to the models of their counterparties; if it is necessary during problem solving, attract new agents from the pool of available agents built by various developers and exclude existing ones, rebuilding “on the fly” the composition of agents and the structure of connections between them.

1 Introduction

Computer modeling of the processes and effects that arise when practical problems are solved by teams of specialists, each of whom has their own rich experience, knowledge and understanding of the subject area, is an important and promising area of scientific research. In particular, almost three decades ago D.A. Pospelov identified it as one of the ten hot spots in artificial intelligence research, on which, according to the author, the efforts of specialists will be concentrated in the next 10 years [1]. However, despite active research in this area at these years, for example, [2-5], the problem of relevant modeling these processes is far from being solved. The reason for this, obviously, lies in the complexity of computer modeling of both the reasoning of individual team members in all their diversity, and the processes, phenomena and effects that arise at the macro level during their interaction while solving problems. Within this study, an attempt is made to model one of the key phenomena that ensures harmonious coexistence and interaction of team members to achieve a common goal, namely reflection. Processes of reflexive imitation of reasoning make it possible to reduce the time spent on redundant communication and ensure the stability of collective reasoning in conditions of the inaccessibility of one or more team members. For computer modeling of the reasoning of teams of specialists with reflexive abilities, it is proposed to create a new class of distributed artificial intelligence systems, namely reflexive-active systems of artificial heterogeneous intelligent agents (RASAHIA), which are proposed to be created within multi-agent approach [6] based on the model of hybrid intelligent multi-agent systems

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[4]. This paper discusses the concepts of basic design principles and the typical functional structure of such systems.

2 Design principles of the reflexive-active systems of artificial heterogeneous intelligent agents

Practical studies [4, 5, 7] of problems arising, in particular, when managing objects of transport logistics, power systems, medicine and other areas, showed the presence of such problem's properties as weak formalization, complex structure, heterogeneity, network nature of conditions and goals, significant opacity (uncertainty) and dynamism [8]. These properties of practical problems predetermine the following design principles of RASAHIA, which, in general, are consistent with the principles of system analysis, general systems theory, synergetics and the construction of reflexive-active environments for innovative development:

- subject-oriented organization of knowledge ("web of concepts"), according to which knowledge is inseparable from cognizing subjects and their subjective realities, and the general picture of the world is formed through the network organization of private subjective pictures of the world and scientific theories [9];
- openness, ensuring the entry of new information, knowledge and agents into the system, maintaining order and its evolution from simple to complex [9];
- homeostasis, combining the ideas of cybernetics, systems analysis, and synergetics. It ensures the functioning of the system within certain frameworks, allowing it to follow its goal-attractor [9]. Homeostasis is ensured by negative feedbacks that suppress external disturbances;
- requisite variety (principle of adequacy), formulated in the systems theory by W.R. Ashby [10] and suggesting that in order to solve a problem that has a certain, known diversity (complexity), it is necessary to create a system with even greater diversity (the presence of problem solving methods) or capable of generating the necessary diversity (to develop relevant problem solving methods) [11];
- polytelicity, according to which the problem for which RASAHIA is created affects many stakeholders with different goals and in order to obtain a solution to the problem that satisfies everyone, it is necessary to take them into account;
- development, which acts as a system-wide basis for social environments that generate innovation. This principle consists of changes in the system with its transition to a state, which is more viable and relevant to existing conditions, and carried out through competition and selection [9]. The principle of development is associated with the principle of openness and allows RASAHIA to take into account the dynamic nature of the problem, adapt to it, while maintaining the relevance of the proposed solutions over time;
- activity, suggesting that RASAHIA agents are active subjects that transform the environment, in which they "live". The subject acts as a determinant of the changes he makes in the world (activity), possessing independence (autonomy), the ability for self-determination (self-regulation, self-organization) and self-improvement [9];
- reflection, which refers to the ability of agents to build models of themselves and other agents or systems, and at the same time "see" themselves building such models [9]. Reflection models reality, turning it into an imaginary reality;
- emergence, according to which RASAHIA has properties greater than the sum of its agents' properties [11];
- hierarchy, which determines the composite nature of the elements of higher levels of the hierarchy relative to lower ones [9].

3 Typical structure of the reflexive-active systems of artificial heterogeneous intelligent agents

In accordance with the principles listed in the previous section, the typical functional structure of RASAHIA has been developed (Figure 1). It describes agent subsystems and their functionality, information flows and relationships between them, as well as their interaction with the external environment, which is considered as a multi-agent system of a higher level. At the same time, each of the system's agents may represent a lower level RASAHIA. This structure acts as a basis for developing a system for a specific problem. When developing such a system, the number and composition of those agents have to be specified, the number of which is not predetermined in the typical structure. The proposed structure consists of four subsystems: interface, technological, management, and problem solving.

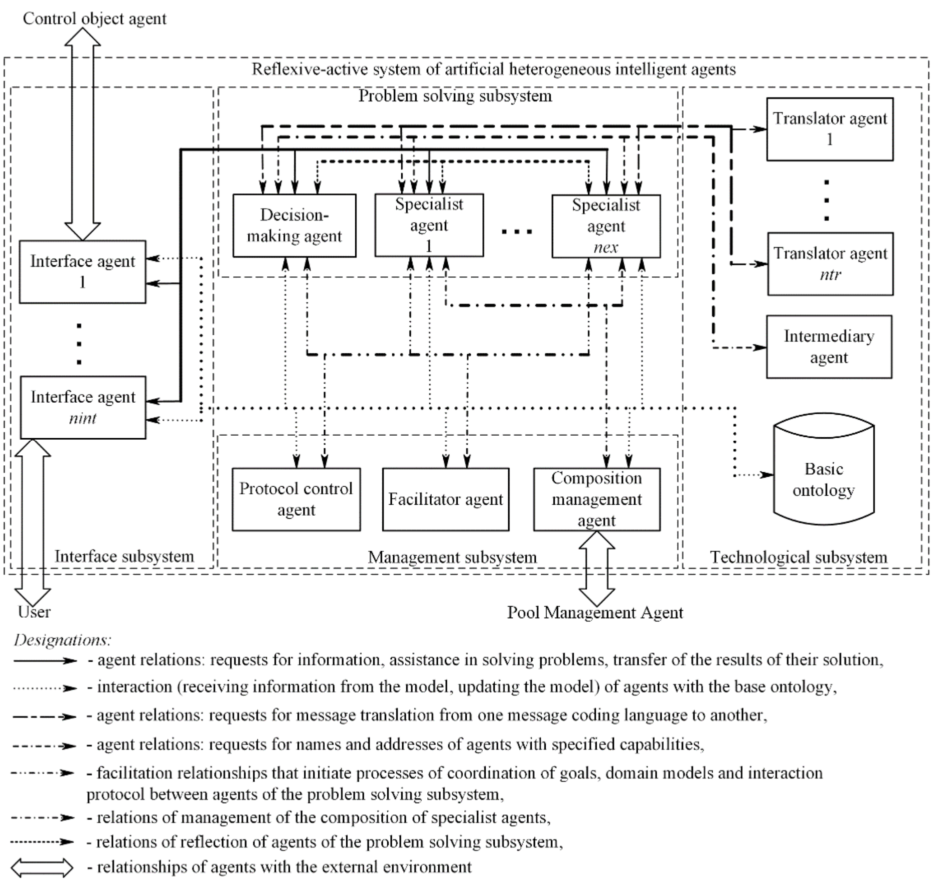

Fig. 1. Functional structure of a reflexive-active system of artificial heterogeneous intelligent agents.

The interface subsystem acts as an intermediary between system agents and its users, as well as the control object. The number of agents of this subsystem can vary and is determined by the approach of the developers of a particular system to the distribution of functionality between agents and the specifics of the problem or class of problems for which RASAHIA is built. The interface agent asks the user for input and presents the result of solving the problem. In addition, it can provide user configuration of the system and visualize the processes occurring in it. If RASAHIA interaction with a control object is expected, it is also carried out through agents of the interface subsystem, which receive information about object's state and issue control actions through application programming interfaces.

Agents and elements of the technological subsystem provide service functions to other agents of the system. Translator agents translate messages from one language to another if a pair of system's agents do not support the same language and cannot communicate with each other directly. The intermediary agent provides system agents with a yellow pages service (searching for and providing agents' names with specific capabilities), tracking the names, models, and capabilities of agents. The basic ontology is a technological element, which ensures that agents understand the message semantics within basic communication by agreeing on their own ontologies, goals and problem solving protocol options.

Agents of the control subsystem ensure effective interaction of other RASAHIA agents and its self-organization. The protocol control agent monitors and controls compliance with the agents' agreements to develop and adjust a problem solving protocol. The facilitator agent ensures effective joint work of agents of the problem solving subsystem, in particular, assesses the current situation in it (determines the stage of solving the problem, established relationships between agents, manifested group effects, etc.), influences its agents, stimulating or resolving their conflicts over goals, ontologies, or problem solving protocol. The composition management agent involves new agents from the pool of available agents and excludes agents from the RASAHIA composition during problem solving. Thus, it ensures the dynamics of the composition of agents, the development of the problem-solving subsystem, and its relevance to the problem posed.

The problem solving subsystem is designed to simulate the work of a group of specialists, modeled by the specialist agents (SA) of the subsystem, on a problem under the guidance of a decision maker, who is modeled by the decision-making agent (DMA). This subsystem ensures the implementation of the principle of requisite variety by modeling the reasoning of specialists in various fields with various problem-solving methods. DMA, having received the information necessary to solve the problem from the interface agent, decomposes the problem into subproblems, after which it distributes them among SA, integrates the results of their work, makes a final decision or initiates re-solving a problem. SA, modeling the reasoning of a real specialist, solves subproblem assigned to it by DMA, or generates an alternative solution to the entire problem. Agents of this subsystem can be created by different developers, which potentially leads to differences and contradictions in their ontologies and goals. However, thanks to reflexive modeling of each other's reasoning, the intensity of conflicts and the duration of negotiations are reduced. In this sense, reflection of agents is a means of synchronization, allowing them to effectively solve a problem by coordinating their own ontologies, goals and problem solving protocol options.

Thus, thanks to the dynamic composition and diversity of agents of the problem solving subsystem, the heterogeneity and variability of the problem is taken into account. RASAHIA agents can be a system of lower-level agents, which provides the principle of hierarchy and allows the problem to be considered at different levels of representation. Reflexive control mechanisms ensure homeostasis of the system due to the agreement by agents of their own goals, ontologies and protocols. The presence of the facilitator agent, who, on the one hand, encourages agents to agree on their goals, ontologies and protocols, and on the other hand, prevents possible negative effects of their excessive consistency, for example, conformism, ensures that the system develops a new hybrid intelligent method for solving each problem. Due to the open nature of RASAHIA and the mechanisms of reflexive control in the system, self-organization of agents in the strong sense arises [12], without centralized control of this process by one of them. This ensures the development of the system in a similar way to long-existing teams of specialists.

4 Conclusion

The paper shows the relevance of computer modeling of collective problem solving for the creation of artificial intelligence systems that allow solving dynamic practical problems no worse than real teams of specialists. The basic design principles and typical functional structure of the proposed new class of distributed artificial intelligence system, namely RASAHIA, are considered. Agents of such systems are active subjects capable of reasoning, communication and reflection, as the ability to model the reasoning of other agents of the system and themselves. Reflexive modeling of each other by agents ensures the development of a coherent representation of the control object, the purpose of collective work and norms of interaction, the building of effective interaction between agents, as well as the evolution of RASAHIA self-organizing in a strong sense.

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