Acta Scientific COMPUTER SCIENCES

Volume 5 Issue 2 February 2023

Review Article

Ensembles of Intelligent Agents with Expanding Communication Abilities

Evgeny Bryndin*

Professional Researcher of Engineering Research Association (AER), Novosibirsk, Russia

***Corresponding Author:** Evgeny Bryndin, Professional Researcher of Engineering Research Association (AER), Novosibirsk, Russia.

Received: November 07, 2022

Published: January 12, 2023

Abstract

Ensembles of intellectual agents solve the problem in the course of self-organization and cooperation according to the criteria of preference and restriction. The solution is considered found when, in the course of their nondeterministic interactions, agents reach the best consensus (temporary equilibrium or balance of interests), which is taken as a solution to the problem. Solving a problem is always seen as an equilibrium when none of the agents can improve their condition anymore, which is evidence of reaching a reasonable compromise, balance of interests, or agreement (harmony) of all intellectual agents in a problematic situation. Agents can act both on behalf of and on behalf of a person, and any physical and abstract entities. In the ensemble of intellectual agents of each entity of the real world, a software agent is put in line, which represents the interests of this entity and can coordinate its decisions with other agents. The advantages of intelligent agents that allow you to build self-organizing ensembles are especially manifested in conditions of a priori uncertainty and high dynamics of the world around you, allowing you to build adaptive ensembles with communicative abilities, rebuilding your plans for events in real time. The higher the intelligence of each agent and the richer the opportunities for communication between agents, the more complex and creative behavior the ensemble can demonstrate. The intellect of the ensemble arises and manifests itself in the process of self-organization of intellectual agents.

Keywords: Ensembles of Intellectual Agents; Self-Organization of Adaptive Ensembles; Preference Criterion; Communicative Abilities

Introduction

Currently, multi-agent technologies are one of the most dynamically developing and promising areas in the field of information and network technologies [1-21]. A booming field is the toolkit for creating multi-agent systems (MAS). The design and implementation of such systems is complex, time-consuming and involves developers having a significant amount of knowledge and experience in thematically different planes - from the presentation and processing of knowledge to the design of distributed applications and an agent of oriented programming.

MAS development tools must provide different activities within the integrated environment. Current trends in this field are associated with the intellectualization of tools based on the use of methods and means of representing and processing knowledge, as well as the integration of such intelligent tools into common technological environments using classical approaches developed and tested in programming technologies. A set of links to the relevant projects is presented on the Intelligent Information Integration website. It includes tools to control the development process, analyze the subject area in which agents should function, design the agent communication environment, specifications for the behavior of individual agents, and debug and test the created software. Agent behavior is described based on special agent communication rules.

The main needs of MAS developers are realized on the basis of intelligent tools. The intelligent toolkit architecturally presents an integrated set of control components, specialized editors and special procedures that provide MAC developers with intelligent assistance in the process of specification of a multi-agent environment as a whole, the behavior of individual agents operating in this environment, as well as the generation of multi-agent applications. The platform development environment contains functions for defining the agent's dynamic model assembly behavior. This feature provides a powerful design mode.

Development begins at the design stage, which is supported by two intelligent components. The first provides identification of the project, management of its implementation and re-engineering of already used project solutions, and the second - control of access to all information on the project.

Interaction is a complex process that provides an understanding of the meaning of transmitted messages and, as a result, the presence of common and shared knowledge. The corresponding activities are supported by three tools. One tool provides the developer with means to identify the created ontology and control the entire process.

Another tool supports two stages of the ontology development process. The knowledge acquisition and conceptualization stage provides a structured specification of all ontology concepts and their attributes, a description of significant relationships between concepts, and the required inference rules related to concepts and relationships. The formalization stage is based on the use of a special language for representing knowledge. This toolkit has an intelligent graphics editor that provides the developer with the means of visual design of ontologies.

The third component implements the last stage of ontology creation - the transformation of the specification into the corresponding library classes and/or into the XML representation of the ontology integrated with the output machine.

The analysis stage closes the turn in the life cycle spiral of the ontology and provides, if necessary, the transition to the next turn of this spiral.

One of the main tasks that arise for MAS developers is to design a multi-agent environment where agents must function.

When an intelligent agent ensemble is designed, its architecture features several agent groups, each led by its own manager. Each group can include different types of agents. The task of group managers is to interact with other managers in order to accumulate information about the composition of groups and the types of agents represented in them, in order to further form intergroup collective communication abilities. After the formation of such collective communication abilities, interaction between their members can be carried out without the intervention of group managers. To do this, you define the message flows that intelligent agents communicate with each other and with the environment.

Process of development of communication abilities of intellectual agent ensembles

The process of developing the communication abilities of intelligent agent ensembles consists of the following stages: analysis, design (external and internal design), implementation, testing, deployment and maintenance (Figure 1). These phases are presented sequentially, although the development process is iterative. Iterations are used both within a phase and in different phases.

Each of the intelligent agents may have multiple lines of behavior that may exist simultaneously and be independent and/or related to each other. The behavior of intelligent agents contains two lines - active and passive. The first of them assumes that the agent implementing it is the initiator of communication, and the second that it only responds to the activity of other agents. Both lines of agent behavior can be activated only if agreed by the interaction partner.

Communications between intelligent agents are independent of the type of network (wired, wireless). They are symmetric on requests, and each intelligent agent can both initiate requests and respond to them. This allows each intelligent agent to dynamically detect and communicate with other agents. Each intelligent agent is identified by a unique name and provides a set of services. It can register and modify its services and/or search for agents providing these services. An intelligent agent is able to control its life cycle. Intelligent agents communicate through asynchronous messaging, a communication model almost universally applicable to distributed and loosely connected communications, i.e. communications between heterogeneous entities that know nothing about each other.

The exchange of messages between the intelligent agents of the ensemble is carried out on the basis of the protocol. Communications provide message security.

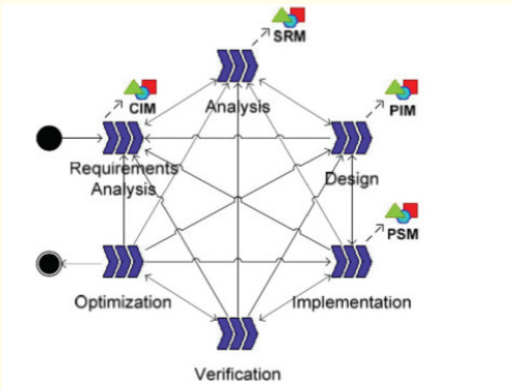

Figure 1: General approach to the development of intellectual agent ensembles.

To facilitate the creation and processing of message content, the technology multi-agent platform provides ensembles with support for automatic direct and reverse conversion to a format suitable for content exchange and a format suitable for content management. This support is built into anthology creation tools, and allows programmers to create ontology graphically. The intelligent agent can stop working on the host and migrate to another remote host. This functionality allows you to distribute the computational load in runtime mode by moving agents to less busy machines. Through these tools, it became possible to remotely manage agents (even when they are already deployed and launched): agent negotiations can be simulated, you can view messages exchanged by agents, you can monitor tasks, and monitor the agent's life cycle. The distributed platform supports agents on various physical systems. The platform provides startup services and root services for agents who wish to communicate with platform services and agents running on the platform. The platform provides a unique name for each registered agent. The platform provides a mechanism for agents to exchange messages through low-level transport communications. The platform provides agents with ways to register their descriptions in order to allow other agents to locate them and find other agents. The platform provides a service to ensembles that provides a function to add new agent types and allows the creation/launch/pause/resume/stop of running agents. Support for agent migration from one technology platform to another is also provided [22].

Intelligent agents interact using three main different techniques: data flows, events, and properties. Event-based connections are used to subscribe an object to events. Each intelligent agent has an event queue that receives event notifications or action requests. Each event contains a Boolean variable that determines whether the event should be processed synchronously in the call thread or if it will be processed asynchronously in a separate thread. This allows you to create special agents in which the set of functions and their complexity depends on the tasks that agents solve. To obtain information about the position of individual agents or agent ensembles, you can send a request to the event scheduler of the corresponding multi-agent platform. The platform execution environment contains additional functions for storing agents, displaying and activating behavior, new capabilities for analyzing and presenting data. Agents interact with their environment using sensors (sensing device) and effectors (action mechanisms). Agents control sensors and effectors. Sensors and effectors accept argument lists. The execution environment is open to extensions and, thus, ensembles of intelligent agents can add their functions if necessary and thereby develop communicative abilities [23-31].

Industrial ensembles of intelligent agents

The creation of virtual enterprises is one of the modern areas of the industry, which is largely stimulated by the rapid growth of information resources and services [32,33]. In addition, the emergence of virtual enterprises is facilitated by a reduction in the lifecycle of created products and an increase in their complexity, as it becomes necessary to quickly combine production, technological and intelligent resources. Another important reason is the tightening of competition in commodity markets, stimulating the unification of enterprises in order to survive.

A virtual enterprise is created as a cooperation of legally independent enterprises, organizations and individuals who produce products or services in a common business process. In the outside world, a virtual enterprise acts as a single organization that uses management and administration methods based on the use of information and telecommunications technologies. The goal of creating a virtual enterprise is to combine production, technological, intellectual and investment resources to market new goods and services.

Each industrial organization within the virtual enterprise performs only part of the work from the general technological chain, then when creating it, two main tasks are solved. The first is the decomposition of the general business process into mini processes. The second task is to choose the rational composition of real partner enterprises that will carry out the technological process. The first task is solved using systems analysis methods, and to solve the second one, ensembles of intellectual agents with developing competencies are involved.

The problem arises of optimal distribution of many mini-processes among many employees of real enterprises.

Its solution begins with the formation of sets of mini processes and potential enterprises of participants. Then, possible mappings from the plurality of participants to the plurality of mini-processes are constructed, and the selection of the most acceptable mapping is made, which corresponds to the specific business process assignments of enterprises. To do this, the auction mechanism is used. Each of the enterprises is represented by an intelligent agent, with one of them acting as a manager.

Before the start of the auction, the manager forms a database and a database of knowledge about the auction participants. It then puts up individual business processes for sale, which are represented by the starting price and requirements for a given set of key figures. Each applicant puts forward their proposals on the parameters that they are able to provide, and their price. Having collected and processed these offers, the auctioneer, using some model of reasoning, orders potential applicants taking into account their own information about them. After that, he decides on the choice of appointments or rejects them and puts forward new proposals.

An ensemble of intellectual agents is engaged in assessing the quality of organizational technical and economic solutions in the course of the enterprise's activities [29].

Currently, there is a transition to a mobile business in which competitiveness and flexibility play a major role. To work in new, rapidly changing environments, enterprises need to constantly transform their production and business process structures. At the same time, it becomes inevitable to attract third-party specialists from the field of technology, marketing, reengineering, etc. Evaluation of proposed solutions is a complex and ongoing activity that requires the participation of highly qualified experts from different areas of knowledge, which are usually geographically distant from each other. This is due to the relevance of distributed computer support for decision-making processes at enterprises, which is implemented by an ensemble of intelligent agents.

To coordinate the work of the team of experts, a two-level coordination mechanism is used. Each of the experts is represented by an agent whose task is to evaluate the alternatives proposed by the manager against a given set of quality indicators. With the help of the knowledge editor, the manager forms tasks for experts and analyzes the information received from them. The task of coordinating the behavior of agents is assigned to the coordinator agent. The result of the system is agreed expert assessments, on the basis of which a lot of criterion ranking of alternatives is carried out.

The work of the ensemble is carried out as follows. The Agent Manager forms tasks, operating reference books containing knowledge about experts, quality indicators and decisions that require consideration. Next, the task as an input message is sent to the coordinating agent, which determines the composition of changes that need to be made in databases at the local level. The Coordinator, using the set of functions provided to him, prepares information for all agents of the experts of the working group. Expert agents perform tasks intended for their users, analyzing messages received from the coordinator, and send him response messages.

The Coordinator Agent collects readiness messages from all team members. When the entire job package is executed, its status changes and a message is sent to the manager agent.

The Agent Manager performs an expert judgment consistency check either on the basis of calculations or by logical analysis of the information provided to him. The decision on the degree of consistency of judgments is sent to the coordinating agent, who advances the task to the next step or returns the experts to the previous stage in order to achieve better consistency.

Conclusion

Intelligent agent ensembles with integrated embodied communications can be widely applied to complex scenarios of both low-level and high-level behavior, both cognitive and physical, and their interactions in embodied agents. Ensembles of intelligent agents with communication abilities enable complex tasks that previously could not be automated; the results of the decision to be issued with a quality comparable to that of a person; Maintain real-time event operations provide the ability to solve the problem in a dialogue with the user; it is easy to parallelize the solution process beyond complex tasks. Modern technologies allow you to create ensembles of intelligent agents with communication abilities, characterized by high openness, flexibility and efficiency, performance, scalability, reliability and survivability, approaching the intellectual abilities of a person and professional teams in their cognitive and functional capabilities and even sometimes surpassing them.

Bibliography

1. J P Bigus. "The Agent Building and Learning Environment". Proceedings of Autonomous Agents 2000, Barcelona, ACM Press (2000): 108-109.
2. Olfati-Saber R and Murray RM. "Consensus problems in networks of agents with switching topology and time-delays". Automatic Control, IEEE Transactions 49.9 (2004): 1520-1533.
3. North MJ., *et al*. "Repast Simphony Development Environment, Proceedings of the Agent 2005 Conference on Generative Social Processes, Models, and Mechanisms, ANL/DIS-06-1, co-sponsored by Argonne National Laboratory and The University of Chicago, Oct. 13-15 (2005).
4. Zambonelli F., *et al*. "Multi-Agent Systems as Computational Organisations: The Gaia Methodology". Agent-Oriented Methodologies, (Eds. Henderson-Sellers B., Giorgini P.) Idea Group Publishing, London (2005).
5. North MJ., *et al*. "Containing agents: Context, Projections and Agents". Proceedings of the Agent 2006 Conference on Social Agents: Results and Prospects, ANL/DIS-06-7, co-sponsored by Argonne National Laboratory and The University of Chicago, September 21-23.
6. Olfati-Saber R., *et al*. "Consensus and cooperation in networked multi-agent systems". Proceedings of the IEEE 95.1 (2007): 215-233.
7. Yong-Zheng Sun and Jiong Ruan. "Leader-follower consensus problems of multi-agent systems with noise perturbation and time delays". *Chinese Physics Letters* 25.9 (2008).
8. Wooldridge M. "An Introduction to MultiAgent Systems". M. Wooldridge. 2nd edition. - Chichester, England : John Wiley and Sons, (2009).
9. Aaron E and Admoni H. "A framework for dynamical intention in hybrid navigating agents". in Hybrid Artificial Intelligence Systems (Berlin, Heidelberg: Springer-Verlag) (2009): 18-25.
10. Chebotarev P Yu and Agaev R P. "Coordination in multiagent systems and Laplacian spectra of digraphs". *Automation and Remote Control* 70.3 (2009): 469-483.
11. Aaron E and Admoni H. "Action selection and task sequence learning for hybrid dynamical cognitive agents". *Robotics and Autonomous Systems* 58 (2010): 1049-1056.
12. Aaron E and Mendoza J P. "Dynamic obstacle representations for robot and virtual agent navigation". in Proceedings of the Canadian Conference on Artificial Intelligence (Heidelberg, New York: Springer-Verlag), 1-12.
13. Aaron E., *et al*. "Integrated dynamical intelligence for interactive embodied agents". in ICAART 2011 Proceedings of the 3rd International Conference on Agents and Artificial Intelligence (Setubal: SCITEPRESS), 296-301.
14. Chen Yao., *et al*. "Multi-agent systems with dynamical topologies: Consensus and applications". IEEE Circuits and Systems Magazine 13.3 (2013): 21-34.
15. Lewis FL., *et al*. "Cooperative Control of Multi-Agent Systems: Optimal and Adaptive Design Approaches (Communications and Control Engineering)". Springer (2014).
16. Camara M., *et al*. "A Multi-Agent System with Reinforcement Learning Agents for Biomedical Text Mining". Proceedings of the 6th ACM Con-ference on Bioinformatics, Computational Biology and Health Informatics. Atlanta (2015): 634-643.

17. Denis Deryugin. “Applying multi-agent technologies to control a group of robotic devices. Fundamental Informatics and Information Technology Mathematical and Software Support for Computers, Computer Systems and Networks”. Saint Petersburg State University (2017): 1-30.

18. G Lombardo., *et al*. “A Multi-Agent Architecture for Data Analysis”. *Future Internet* 11 (2019): 1-12.

19. Koshur VD., *et al*. “Implementation of a multi-agent artificial intelligence system to solve the classification problem”. Neuroinformatics-2019: materials of an international scientific and technical conference. Moscow: MIPT Publishing House, (2019): 24-31.

20. Lean Yu., *et al*. “A Multi-Agent Neural Network System for Web Text”. *Emerging Technologies of Text Mining* (2020).

21. Burlutsky VV., *et al*. “Development of a multi-agent intellectual system for solving the problems of classification and ranking of materials on the Internet”. *Bulletin of the South* 16.3 (2020): 47-52.

22. Evgeny Bryndin. “Cross-Platform Collaboration with Help Virtual Digital Thinking of Technological Mind with Artificial Intelligence”. *Integrative Journal of Conference Proceedings* 3.1 (2022): 1-4.

23. Evgeniy Bryndin. “Collaboration of Intelligent Interoperable Agents via Smart Interface”. *International Journal on Data Science and Technology* 5.4. (2019): 66-72.

24. Evgeniy Bryndin. “Development of Artificial Intelligence by Ensembles of Virtual Agents with Mobile Interaction”. *Automation, Control and Intelligent Systems* 8.1 (2020): 1-8.

25. Evgeniy Bryndin. “Technology Self-organizing Ensembles of Intelligent Agents with Collective Synergetic Interaction”. *Automation, Control and Intelligent Systems* 8.4 (2020): 29-37.

26. Evgeny Bryndin. “ Functional and Harmonious Self-Organization of Large Intellectual Agent Ensembles with Smart Hybrid Competencies”. *American Journal of Software Engineering and Applications* 10.1 (2021): 1-10.

27. Evgeny Bryndin. “Simulation of creative manifestation by functional ensembles of intellectual agents based on live information in various spheres of life activity”. *Network and Communication Technologies* 6.2 (2021): 41-46.

28. Evgeny Bryndin. “Modeling of creative and professional activities by ensembles of intellectual agents based on live information”. *International Journal of Artificial Intelligence and Mechatronics (IJAIM),* 10.4 (2022): 44-50.

29. Evgeny Bryndin. “Ensembles of Intellectual Agents with Decision-Making”. *Acta Scientific Computer Sciences* 4.6 (2022): 03-08.

30. Evgeny Bryndin. “Intellectual Agent Ensemble with Professional Competencies, Pattern Recognition and Decision Making”. *Applied Science and Innovative Research* 6.4 (2022): 1-10.

31. Evgeny Bryndin. “Identification of Natural Novelty and Disasters by Ensembles of Intelligent Agents Based on Spectral Measurement”. *International Journal of Innovative Research in Multidisciplinary Education* 1.2 (2022): 55-59.

32. Evgeniy Bryndin. “Formation and Management of Industry 5.0 by Systems with Artificial Intelligence and Technological Singularity”. *American Journal of Mechanical and Industrial Engineering* 5.2 (2020): 24-30.

33. Evgeny Bryndin. “Implementation of Competencies by Smart Ethical Artificial Intelligence in Different Environments”. *Software Engineering* 8.4 (2021): 24-33.