ХАБАРЛАРЫ

ИЗВЕСТИЯ

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ГЕОЛОГИЯ ЖӘНЕ ТЕХНИКАЛЫҚ ҒЫЛЫМДАР СЕРИЯСЫ

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СЕРИЯ ГЕОЛОГИИ И ТЕХНИЧЕСКИХ НАУК

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SERIES OF GEOLOGY AND TECHNICAL SCIENCES

3 (429)

NAS RK is pleased to announce that News of NAS RK. Series of geology and technical sciences scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of News of NAS RK. Series of geology and technical sciences in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential content of geology and engineering sciences to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Известия НАН РК. Серия геологии и технических наук» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Известия НАН РК. Серия геологии и технических наук в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному контенту по геологии и техническим наукам для нашего сообщества.

UDC 004.89

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ANALYTICAL REVIEW OF SOFTWARE
FOR MULTI-AGENT SYSTEMS AND THEIR APPLICATIONS

Abstract. In this article there was conducted an analytical review of the most common modern software and implemented on their basis practical applications. There is considered the history of development of multi-agent systems (MAS). The relevance of the use of multi-agent technologies for the creation of information systems for the complex objects modeling based on various methods and algorithms is noted. There were considered the most widespread agent-oriented platforms of multi-agent systems, the comparative analysis of their characteristics and presented the development tools was carried out. The examples of modern multi-agent applications implemented with the help of these software products in industry, science and education were presented. The features of applications functioning in the production of goods and services, as well as of complex processes modeling were pointed out. Particular attention is paid to the Java Agent Development Framework (JADE), presented the structure, main functions and methodology of the multi-agent systems development. The advantages of multi-agent systems (flexibility of operation, operational interaction between agents, optimal distribution of computing resources, self-organization and multifunctionality) at creating innovative intellectual technologies based on different approaches applying and on system analysis were shown. There were analyzed the features of agent technologies and prospects of their use for the development of complex multi-user programs.

Keywords: multi-agent systems, analytical review, software.

Introduction. The development of powerful personal computers with high computing productivity and with large memory capacity, as well as the need to process large amounts of information led to the development of new intelligent technologies based on various modern approaches. Multi-agent systems (MAS), in which interacting agents are used for solving complex problems, have become widespread. Many MASs are the basis of large-scale open, decentralized systems, which consist of autonomous components with such features as reactivity, proactivity, and the ability for flexible interactions to achieve their goals [1]. Under the term reactivity of agents, there is meant the ability of agents placed in the environment to perceive this environment and to react to changes occurring in it. Proactivity is the properties of agents in order to solve problems in the environment on their own initiative. In MAS agents interact with each other, and also make independent decisions based on the implementation of certain algorithms to achieve the set goals.

Multi-agent systems have a 40-year history [2, 3]. At the end of 1990, there was a significant interest to self-organizing MAS. A lot of scientific works are devoted to the study of MAS, among which there are works by Ferber J., Schumacher M [4], Roberto A. Flores-Mendez [5], Chavez A. [6], Brooks T., Finin N. Jennings, Wooldridge M., B.I. Gorodetsky, V.B. Tarasova, V.F. Khoroshevsky and others. The most famous works are by Jacques Ferber [7], who was one of the first in France in the 90s to publish works on the MAS. In 2000-2005 there was created a working group "Self-organizing MAS" based on the European project program FP3-5 "AgentLink", which gave a powerful impulse for the researches and development in this field.

The relevance of MAS developing is determined by the need to solve complex problems that are characterized by high complexity of calculations, parameters uncertainty and functioning in real time. The

main advantages of MAS are the optimal distribution of computing resources, flexibility (the system can be supplemented and modified), self-organization, self-recovery and fault tolerance, multifunctionality, etc.

The article gives an overview of the main agent-oriented platforms, their advantages and sphere of their application. There are considered the examples of modern software products application implementing a multi-agent approach to real applications in various fields of science and technology. Particular attention is paid to the multi-agent platform JADE, as to the most widespread and open system for the development of MAS. At the end, there is given a conclusion on the results of the analytical review.

Multi-agent platforms review. There is a large number of software implementing the MAS. The most famous platforms are: JADE (Java Agent Development Framework [5]), JACK Intelligent Agents [17], MadKIT (Multi-Agent Development Kit [18]), Agent Builder [23], Cougaar (Cognitive Agent Architecture [27]), Zeus (Agent Building Tool-kit) [34], MASON (Multi-Agent Simulator Of Neighborhoods [36]), etc.

Most of the presented platforms are based on the Java programming language, which allows to develop multi-agent applications on a cross-platform basis, that is, to run the final software product in various operating systems. Each platform has its own characteristics. Most multi-agent platforms have an open license and are distributed free of charge. Paid platforms (for example, Agent Builder) are closed and do not allow to change the initial code. Each software is characterized by its own tools and development models, and also has various applications.

Table 1 presents the most known multi-agent platforms and their characteristics.

Table 1 – Multi-agent platforms

#	Platform	License	Development tools
1	JADE (Java Agent Development Framework)	open (GNU Lesser General Public License)	Agent Management System, Director Facilitor, Agent Communication Channel
2	MadKIT (Multi-Agent Development Kit)	open (CEA CNRS INRIA LogicielLibre)	Agent/Group/Role model, Organization-centered Multiagent System
3	JACK Intelligent Agents	open (Proprietary software)	Belief-Desire-Intention Model, JACK Development Environment (JDE), JACK Object Modeller (JACOB), JACK Plan Language (JPL), Agent Run-time
4	Agent Builder	closed (not free of charge)	Project Control Tools, Ontology Manager, Agency Manager, Agent Manager, Agent Debugger
5	Cougaar (Cognitive Agent Architecture)	open (Cougaar Open Source License)	Blackboard, Http servlet engine, Knowledge representation system
6	Zeus (Agent Building Tool-kit)	open (free initial code)	Three layers of agents, Role Modeling
7	MASON (Multi-Agent Simulator of Neighborhoods)	open (free initial code)	2d and 3d Libraries

1. JADE (Java Agent Development Framework) [5] – a widely used software platform that is an effective tool for the development of applications based on MAS. The platform has three main modules in accordance with FIPA standards (Foundation for Intelligent Physical Agents). Agent Management System AMS controls the registration and authentication of agents, manages the life cycle of all agents within it, and also provides services of white pages (the register of existing agents). The DF (Director Facilitor) module provides yellow page services (the register of agent services registered in the AMS). The third module ACC (Agent Communication Channel) controls the communication between agents. The structural diagram of JADE is shown in figure 1.
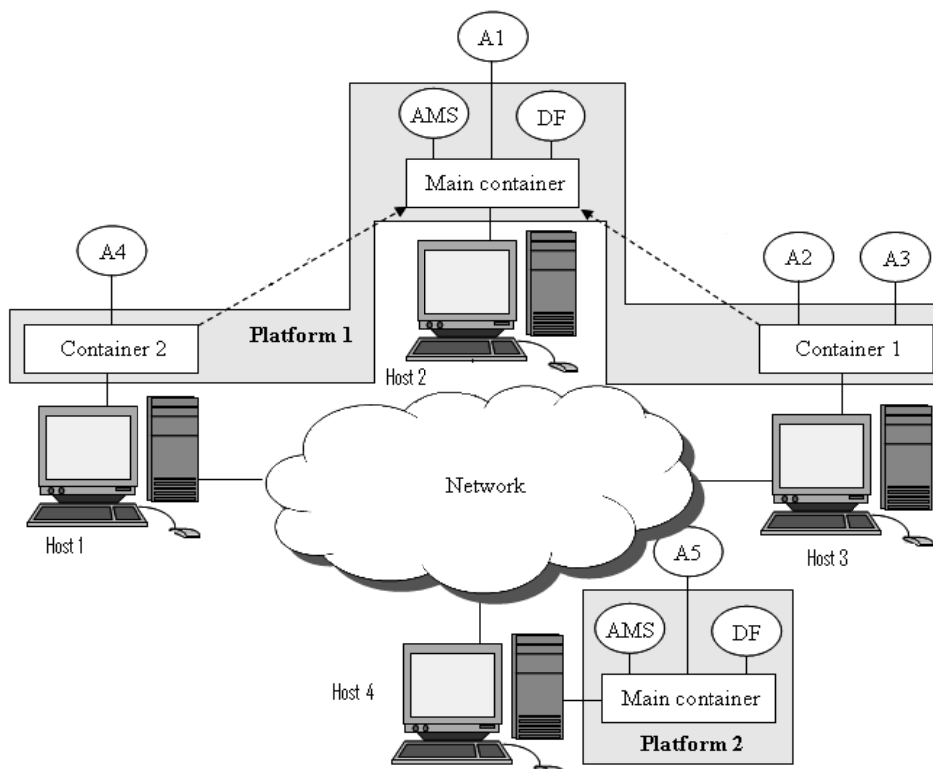
Figure 1 – Java Agent Development Framework multi-agent platform

Working with the multi-agent platform JADE there are used the standard agents Dummy Agent and Sniffer Agent, which are system controllers responsible for the operation of the main container. In order to transfer information between agents there is used a ready agent Dummy Agent, the parameters of which are specified in the additional user interface. Another ready-made tool Sniffer Agent allows to view the transmitted data between agents and to write them to the Log Manager.

Agents communicate through the ACL (Agent Communication Language) FIPA language and can communicate, regardless whether they are in the same container (for example, A2 and A3) or on different platforms (for example, A1 and A5). The communication is based on the paradigm of asynchronous messaging. The message format is built in ACL (Agent Communication Language) language, which consists of such fields as: sender, recipient, communication and content. The communication field indicates the intention to transfer information to another recipient and sends a message through the sender. The content field contains the type of processed information. In JADE the message elements can be of the primitive type (logical expression, digit, line) or of the aggregate type (user-defined structure consisting of primitive or of set of elements). Aggregate elements are usually represented as Java, XML, and bytecode classes.

Multi-agent applications based on JADE are widely used in industry, education and science. In the technology of industrial agents [9, 10] there are used the advantages of distributed computing, artificial intelligence (AI) methods and semantics in production and services spheres. In real applications, there is provided a new method of design and control based on decentralized control over distributed structures. Advantages of industrial systems based on agents are: reliability, scalability, flexibility and productivity. For example, the work [11] presents a system of information processes modeling using JADE. There is used a library that integrates in JADE and allows the proper distribution of resources. As a result of comparative tests, it was proved that in practice this modeling based on agents shows the best results.

Also, JADE is widely used in the creation of information systems in the field of education. The article [12] presents a multi-agent smart-system of distance learning (DL) for people with impaired vision (PIV). The multi-agent approach is used to optimize the functioning of the information system of DL based on intellectual, cognitive and statistical methods. In order to optimize the work of DL for PIV, the

agents were distributed by containers in the JADE software environment. In work [13] there was developed a multi-agent system which is used to search and to submit training materials stored on various servers. This model is developed using JADE and the standard of metadata LOM (Learning Object Metadata), which has a hierarchical structure and provides quick access to information. The multi-agent technology improves the effectiveness of the search for educational materials. The article [14] presents a multi-agent system, which is designed to facilitate the acquisition of knowledge by older people. The advantage of the proposed approach is the possibility of using mobile devices that increase the availability of learning for dependent people. In work [15] there is considered a multi-agent model for the computer support system for collective learning. The model is aimed at identifying conflicts that have arisen in groups for improving co-education, as well as for personal training of group members. By analyzing the processes of interaction between groups, the conflicts are recognized. In order to determine the most appropriate learning strategy, the joint characteristics of students are taken into account. A similar MAS is presented in the article [16]. There is used a problem-based learning model (PBL, Problem-Based Learning) to detect passive students in a virtual DL environment. The system is designed to identify undesirable situations and to improve the learning process.

2. MADKit (Multi Agent Development Kit) [17] - is a modular and scalable multi-agent platform with open initial code written in Java and built using the AGR (Agent / Group / Role) model. The platform allows to create the distributed applications and to conduct modeling using a multi-agent paradigm. One of the key aspects of MADKit is that in comparison with conventional approaches that are mostly agent-oriented MaDKit uses the OCMAS (Organization-centered Multi- AgentSystem) approach. The main features of MaDKit are:

- the creation of intelligent agents and lifecycle control;

- the creation of an infrastructure that is used to provide communication between agents and for the structuring of multi-agent models;

- the development of distributed applications based on a set of agents.

Based on MADKit there are created the majority of multi-agent applications in the field of modeling for the industry. In work [18] there is proposed the multi-agent system IDS (Intrusion Detection System), which uses the advantages of mobile agents to improve the output of network channels. Mobile agents provide network security. In work [19] there is proposed the MAS for control and optimization the heating and ventilation processes inside the smart building. This MAS is designed to maintain a high level of comfort for residents, for minimization energy consumption and for reduction of its cost. Experimental results and their analysis confirm the effectiveness of the created MAS.

3. JACK Intelligent Agents – software complex [20] is a cross-platform environment for the creation and integration of commercial industrial systems. The complex is built on an efficient logical basis BDI (Beliefs/Desires/Intentions). In JACK there are created the agents taking into account beliefs, desires and intentions for the realization of their own goals. System packers with a high degree of encapsulation are responsible for the work of agents. Each agent is determined depending on its goals, knowledge and communication capabilities, and then autonomously performs its individual function in the environment. This approach in JACK is an effective way to create applications for dynamic and complex environments. Each agent is responsible for the implementation of its own goals, responds to events in the environment and communicates with other agents.

The key advantage of [21] JACK is an efficient cross-platform platform:

- low requirements for computing resources, designed for processing hundreds of agents working on low-level hardware;

- "transparent" communication between agents;

- the availability of a graphical tool for developing agents.

For example, the article [22] presents the dynamic planning MAS for production of MFL (Manufacturing Flow Lines) using the JACK-based Prometheus (PM) design tools. The PM methodology is used to develop a decision-making system with the possibility of dynamic restructuring. Each agent in the MAS is autonomous and has the ability to interact with other agents. The proposed decision-making system supports both static and dynamic planning.

4. Agent Builder [23] – is an integrated set of tools for creating intelligent software agents. Agent Builder consists of two main components: the toolkit and the compilation environment. The Agent Builder

toolkit includes: tools for controlling the development of multi-agent software, for analyzing agent transactions, for designing and developing interrelated agents, for determining the behavior of individual agents, and tools for agents debugging and testing. The agents created with the help of Agent Builder communicate using the knowledge management language and KQML (Knowledge Query and Manipulation Language) requests and support many functions for information exchange.

Agent Builder Toolkit is designed for quick and easy creation of intelligent agents and multi-agent software on a commercial basis. It has flexible tools for organizing the projects that allow the MAS developer effectively to manage the process of creating the entire software. This toolkit contains:

- Ontology Manager, which assists the developer in analyzing the agent's problem area and in determining the structure relevant to the agent's work in this area.

- MAS Manager (Agency Manager) provides a temporary user window for viewing the operation of the entire agent system. Therefore, the developer can monitor and manage inter-agent communications, and also run a debugger to check the status of individual agents.

- Agent Manager has a tool for configuring the behavior of an individual agent. This tool includes a graphical editor for setting the initial characteristics of an agent: beliefs, commitments, intentions, opportunities and behavior. In addition, the agent manager provides the ability to plan and to train the agent.

- Agent Debugger provides the means to communicate with the executing agent, and also enables the software developer to detect system errors. Therefore, Agent Builder reduces time and development costs and simplifies the creation of high-performance, fault tolerant multi-agent applications.

There are many commercial high-performance systems [24]. The article [25] presents an intelligent factory control system that includes an industrial network, a cloud storage and dispatcher control terminals for facilities (machines, conveyors and products). These objects are classified by different types of agents, which are coordinated and controlled in the cloud space. On the basis of self-organizing MAS the work of the factory's infrastructure is coordinated through the feedback.

In the research [26] there are considered the MAS for solving the problems of production automation. There were developed the agents for the physical equipment control, which is implemented on the basis of special standards of industrial control.

5. *Cougaar (Cognitive Agent Architecture)* [27] – is a Java architecture for the creation of large-scale applications based on distributed agents. The Cougaar architecture is an open initial code that describes the class structure and basic service procedures for the creation of multi-agent applications. The Cougaar platform allows the creation of large-scale distributed systems consisting of a large number of agents. Organization of the agents work at the creation of applications is carried out using peer-to-peer groups that can effectively perform localized functions. As a result, communities are created, consisting of a set of agents.

The structure of Cougaar agents includes several integrated extended services:
- "blackboard" is intended for communication of agents among themselves;
- HTTP services (Hyper Text Transfer Protocol) for user interfaces;
- knowledge representation systems;
- coordination between the agents through the mechanisms of assignments.

With the use of Cougaar there are created applications in the field of logistics [28-30], modeling and technical objects support. The article [31] there was developed a cyber-physical system based on MAS in order to solve the problem of optimizing urban traffic. An effective mechanism is introduced in order to control the traffic taking into account the infrastructure, which allows to analyze the traffic capacity and to recognize its participants. The ontology, which acts as a knowledge base. is included in the traffic control system. The research [32] considers an adaptive MAS based on the behavior of an ant colony and a hierarchical fuzzy model. This system allows effectively to regulate the traffic in accordance with the changes in road networks in real time. The article [33] proposes an integrated approach for modeling the transport infrastructure and for optimization the traffic around the city. In order to create an extensive multi-layer transport network, there are modeled various intelligent transport agents taking into account the roads, tram and bus routes, bicycle paths, pedestrian paths. Direct interaction is provided between the mobile devices of the users and the MAS in order to send travel requests.

6. *Zeus (Agent Building Tool-kit)* [34] is a graphical environment for creating systems based on distributed agents. It includes tools for development, planning and visualization. Platform agents have

three levels. In the first level, the agent is viewed as an autonomous object that can act according to his beliefs, resources and preferences. In the second level, the agent is defined as the organization in which the relationship between agents, protocols and other interaction mechanisms is examined. The third level serves for coordination, where each agent is viewed as an object with its own communication and control skills. In Zeus there is used the "RoleModeling" approach based on the distribution of agents by functional roles.

The main features of the Zeus Agent Toolkit are the modeling of complex processes. Applications based on the Zeus Agent Toolkit can be used to solve problems in the oil and gas industry. The work [35] presents the MAS, the agents in which successfully solve complex and distributed problems related to the production, storage, transportation and processing of petroleum products.

7. MASON (Multi-Agent Simulator of Neighborhoods) [36] - is a high-performance Java platform for multi-agent modeling of various processes, which has opportunities for graphical representation in two-dimensional and three-dimensional forms.

This platform has the following advantages:
− speed of data processing;
− small requirements for computing resources;
− possibility of integration with other applications;
− 2D and 3D visualization.

The MASON platform is used to develop practical applications for solving various tasks, for example:
− urban traffic modeling;
− surveillance of unmanned aerial vehicles, etc.

Using MASON [37] there was developed a multi-agent model of urban traffic in order to study the cars movement and to analyze its flows. Modeling predicts the occurrence of cars at intersections, taking into account the distance and speed of movement. It also takes into account the work of traffic lights, which are involved in the traffic distribution. With the help of this system, there are solved the problems of the transport optimal distribution along the roads.

In work [38] there is considered the effectiveness of the application of various algorithms for agents of observers. Observers and objects are modeled in a virtual environment (2D or 3D) in real time. There is formed a joint target surveillance environment in which customizable algorithms are implemented.

The article [39] presents researches aimed at developing an application on the basis of MAS for the mobile health application SMPHR (Self-Management mobile Personal Health Record). The system is designed for continuous care of patients with chronic diseases. The SmPHR application was developed for the mobile operating system Android 4.0.3 and implemented in accordance with standard health protocols. As a result, SmPHR can provide patients with mobile medical care and connect them to various devices via standard protocols.

Conclusion. Therefore, as a result of the conducted analytical review, there were considered the widespread agent-oriented MAS platforms and was carried out a comparative analysis of their characteristics. There were presented examples of practical multi-agent applications implemented with the help of the software in various fields of industry, science and education. Particular attention is paid to the Java Agent Development Framework (JADE), were shown the structure, main functions and methodology of the MAS development.

Advantages of MAS:
− flexibility of functioning;
− operational interaction between agents;
− optimal distribution of computing resources;
− the ability to learn and solve specific and global problems;
− autonomy, limited representation, decentralization of agents;
− self-organization;
− multifunctionality;
− reliability and resistance to failures.

The article deals with the features of agent technologies and the prospects of their use in the development of complex multi-functional applications. There were noted the actual directions of MAS, the possibility of creating and implementing mechanisms that allow agents dynamically to change the nature of interaction, and also to adjust goals, depending on changing conditions.

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МУЛЬТИАГЕНТТІК ЖҮЙЕЛЕР МЕН ОЛАРДЫҢ ҚОСЫМШАЛАРЫН ПРОГРАММАЛЫҚ ҚАМТАМАСЫЗ ЕТУІНЕ АНАЛИТИКАЛЫҚ ШОЛУ

Аннотация. Мақалада кең таралған заманауи бағдарламалық қамтамасыз ету мен оның негізінде жүзеге асатын тәжірибелік қосымшаларға талдау жүргізілді. Мультиагенттік жүйелердің (МАЖ) даму тарихы қарастырылды. Әртүрлі әдістер мен алгоритмдер негізінде күрделі объектілерді моделдеу үдерісі үшін ақпараттық жүйелерді құрудағы мультиагенттік технологияларды құрудың өзектілігі келтірілген. Мультиагенттік жүйелердің агентті-бағытталған платформалары қарастырылған, сипаттамаларына салыстырмалы талдау жасалып, оларды құру құралдары келтірілген. Өндірісте, ғылым мен білім беруде қолданысқа ие бағдарламалық өнімдердің негізінде жүзеге асқан заманауи мультиагенттік қосымшалардың мысалдары келтірілген. Тауар өндіру саласы мен қызметі, сондай-ақ күрделі үдерістерді моделдеуде пайдаланатын қосымшалар қызметінің ерекшелігі айқындалды. Java Agent Development Framework (JADE) платформасына ерекше мән беріліп, оның құрылымы, негізгі функциялары мен мультитагенттік жүйелерді құрудың әдістемесі

келтірілген. Жүйелік талдау мен түрлі тәсілдерге негізделген инновациялық интеллектуалды технология-ларды құруда қолданылатын мультиагенттік жүйелердің артықшылықтары (функционалдану иілгіштігі, агенттердің арасында шұғыл өзара байланыс орнату, есептеуіш қорларды оңтайлы тарату, өзара ұйым-дастыру мен көп функционалдық) ұсынылған. Агенттік технологиялардың ерекшеліктері мен күрделі көп пайдаланушылық бағдарламаларды құруда қолданылу болашағы талданды.

Түйін сөздер: мультиагентті жүйелер, аналитикалық шолу, бағдарламалық қамтамасыз ету.

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АНАЛИТИЧЕСКИЙ ОБЗОР ПО ПРОГРАММНОМУ ОБЕСПЕЧЕНИЮ МУЛЬТИАГЕНТНЫХ СИСТЕМ И ИХ ПРИЛОЖЕНИЙ

Аннотация. В данной статье проведен аналитический обзор наиболее распространенного современного программного обеспечения и реализованных на их основе практических приложений. Рассмотрена история развития мультиагентных систем (МАС). Отмечена актуальность применения мультиагентных технологий при создании информационных систем для процессов моделирования сложных объектов на основе различ-ных методов и алгоритмов. Рассмотрены наиболее распространённые агентно-ориентированные платформы мультиагентных систем, осуществлен сравнительный анализ их характеристик и приведены инструменты разработки. Представлены примеры современных мультиагентных приложений реализованных с помощью этих программных продуктов в промышленности, науке и образовании. Выделены особенности функцио-нирования приложений в сфере производства товаров и услуг, а также моделирования сложных процессов. Особенное внимание уделено платформе Java Agent Development Framework (JADE), приведены структура, основные функции и методология разработки мультиагентных систем. Показаны достоинства мульти-агентных систем (гибкость функционирования, оперативное взаимодействие между агентами, оптимальное распределение вычислительных ресурсов, самоорганизованность и многофункциональность) при создании инновационных интеллектуальных технологий, основанных на применении различных подходов и систем-ном анализе. Проанализированы особенности агентных технологий и перспективы их использования для разработки сложных многопользовательских программ.

Ключевые слова: мультиагентные системы, аналитический обзор, программное обеспечение.

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ISSN 2518-170X (Online), ISSN 2224-5278 (Print)

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