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SIMULATION OF RESOURCE DISTRIBUTION IN LARGE INFORMATION SYSTEMS BASED ON MULTIAGENT APPROACH

Abstract: *Traditional planning theory considers the general problem of division of labor on computing devices. A fairly large class of planning tasks is included in the described task of resource allocation. The only type of resources in such tasks are computing resources. The article considers the tasks of resource allocation in multi-agent systems, options for their applicability and existing methods of solving these problems. The task of allocating resources is one of the fundamental tasks: from the efficient allocation of one's own time to the distribution between different activities and the tasks of allocating resources in large information systems. The article considers different approaches to resource allocation in large information systems: resource allocation within non-stationary tasks, stationary tasks and in multi-agent systems. These approaches help to solve various applications in real time. In the case of resource allocation in multi-agent systems, their decentralization must be taken into account: agents are directly responsible for themselves and do not have complete information about the system, which changes the very essence of the task. Thus, the development of multi-agent models is possible. The multi-agent scheduling methods used in the system can be used in real-time decentralized systems compared to the previously mentioned traditional methods. Their application provides management of planning and execution of tasks, they can be used to manage groups of objects consisting of a large number of devices and able to quickly process large-scale tasks. Thus, in a short time it is possible to design and commission based on the use of multi-agent technologies for planning new-generation software and hardware systems that can interact and work in a group and applicable to a wide range of tasks in various fields.*

Keywords: *multi-agent system, multi-agent approach, information systems, resource allocation, optimization.*

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МОДЕЛЮВАННЯ РОЗПОДІЛУ РЕСУРСІВ У ВЕЛИКИХ ІНФОРМАЦІЙНИХ СИСТЕМАХ НА ОСНОВІ МУЛЬТИАГЕНТНОГО ПІДХОДУ

Анотація: *Традиційна теорія планування розглядає загальну задачу розподілу робіт по обчислювальних пристроях. Досить великий клас задач планування входить в описану задачу розподілу ресурсів. Єдиним видом ресурсів в таких завданнях є обчислювальні ресурси. У статті розглядаються завдання розподілу ресурсів в мультиагентних системах, варіанти їх застосовності і існуючих методів вирішення цих завдання. Завдання розподілу ресурсів є одним із фундаментальних завдань: від ефективного розподілу свого власного часу до розподілу між різними видами діяльності і завданнями розподілу ресурсів у великих інформаційних системах. У статті розглянуті різні підходи до розподілу ресурсів у великих інформаційних системах: розподіл ресурсів в рамках нестаціонарних задач, стаціонарних задач та в мультиагентних системах. Перераховані підходи допомагають вирішувати різні прикладні задачі в режимі реального часу. У разі розподілу ресурсів в мультиагентних системах треба враховувати їх децентралізацію: агенти безпосередньо відповідають тільки за себе і не мають повної інформації про систему, через що змінюється сама суть завдання. Таким чином, розробка мультиагентних моделей можлива. Використовувані в системі методи мультиагентного планування порівняно з раніше зазначеними традиційними способами можуть застосовуватися в децентралізованих системах в реальному часі. Їх застосування забезпечує управління процесами планування і виконання завдань, вони можуть бути використані для управління групами об'єктів, що складаються з великої кількості пристроїв і здатні оперативно обробляти завдання великого об'єму. Таким чином, у короткі строки можливо проектування та введення в експлуатацію заснованих на використанні мультиагентних технологій* *планування програмно-апаратних комплексів нового покоління, здатних взаємодіяти і працювати в групі і застосовних для широкого спектру завдань в різноманітних областях.*

Ключові слова: *мультиагентна система, мультиагентний підхід, інформаційні системи, розподіл ресурсів, оптимізація.*

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МОДЕЛИРОВАНИЕ РАСПРЕДЕЛЕНИЯ РЕСУРСОВ В БОЛЬШИХ ИНФОРМАЦИОННЫХ СИСТЕМАХ НА ОСНОВЕ МУЛЬТИАГЕНТНОГО ПОДХОДА

Аннотация: *Традиционная теория планирования рассматривает общую задачу распределения работ по вычислительным устройствам. Достаточно большой класс задач планирования входит в описанную задачу распределения ресурсов. Единственным видом ресурсов в таких задачах есть вычислительные ресурсы. В статье рассматриваются задачи распределения ресурсов в мультиагентных системах, варианты их применимости и существующие методы решения этих задач. Задача распределения ресурсов является одной из фундаментальных задач: от эффективного распределения своего времени до распределения между различными видами деятельности и задачами распределения ресурсов в крупных информационных системах. В статье рассмотрены разные подходы к распределению ресурсов в больших информационных системах: распределение ресурсов в рамках нестационарных задач, стационарных задач и в мультиагентных системах. Перечисленные подходы помогают решать разные прикладные задачи в режиме реального времени. В случае распределения ресурсов в мультиагентных системах следует учитывать их децентрализацию: агенты непосредственно отвечают только за себя и не имеют полной информации о системе, из-за чего изменяется сама сущность задачи. Таким образом, разработка мультиагентных моделей возможна. Используемые в системе методы мультиагентного планирования по сравнению с ранее отмеченными традиционными способами могут применяться в децентрализованных системах в реальном времени. Их приложение обеспечивает управление процессами планирования и выполнения задач, они могут быть использованы для управления группами объектов, состоящими из большого количества устройств и способны оперативно обрабатывать задачи большого объема. Таким образом, в короткие сроки возможно проектирование и ввод в эксплуатацию основанных на использовании мультиагентных технологий планирования программно-аппаратных комплексов нового поколения, способных взаимодействовать и работать в группе и применимых к широкому спектру задач в различных областях.*

Ключевые слова: *мультиагентная система, мультиагентный подход, информационные системы, распределение ресурсов, оптимизация.*

1. Introduction. In modern trends in the development of computer technology, decentralized approaches to the organization of computer systems are becoming increasingly important. Thus, the approaches that initially mean a decentralized computer system become interesting. A common view of such approaches is multi-agent systems, which are being actively developed today. However, it should be noted that due to the initial decentralization, there is a general tendency for such approaches not to be optimal due to the lack of all necessary information about the system for individual agents, which is usually offset by the lack of centralized computing. Consideration approaches provide an opportunity to optimize the task of resource allocation in large information systems.

2. Analysis of recent research and publication. An analysis of recent publications shows that scientists around the world are actively conducting research in the field of optimizing the allocation of resources in large information systems.

In the article [1] Yaremenko V.S. the analysis of multiagent systems of the analysis of the big volume of the data representing set of intelligent agents is carried out. The analysis process includes a set of steps to integrate data, pre-process data, classify data, define rules, and present a database. Due to the parameters of autonomy, mobility and adaptability, the use of intelligent agents is considered an effective solution for parallel and distributed data analysis [2]. Studies of domestic and foreign scientists [3-8] are devoted to the peculiarities of building multi-agent systems and the benefits of approaches, models and architectures that can be used in their development. In the works of Aksak N.G. [9-10] discusses the approaches used in the construction of network services based on multi-agent systems for the distribution of large amounts of data.

Dodonov V.O., Lande D.V., Putyatin V.G. [11] considered the implementation of a multi-agent approach to modeling information-analytical system for further application of the scenario approach. A multi-agent model of dissemination of information messages containing links to information resources on the Internet is presented. In the work of Melnychuk A.V., Sivakova T.V., Sudakova V.A. [12] investigates multi-agent modeling for constrained problem solving, where each agent manages a specific set of variables and interacts with agents who share common constraints with it.

In [13-15] describes the improvement of human resource management in projects for the development and implementation of information systems through the use of multi-agent models, methods and tools based on indicators of competence of human resources that may be involved in project work under uncertainty and formation of these indicators. In the article [16] Omelyanenko V.A. identified the conceptual basis for the development of intelligent project management systems based on a multi-agent approach to the development of complex technological systems. The solution of two optimization problems is considered – resource allocation and coordination of parameters of the designed system. In [17] the system of distributed processing of streaming data and complex events is considered. A mathematical model of consumption and distribution of computing resources in peripheral computing is proposed. Based on the mathematical model, a multi-agent algorithm was developed as part of the agent software architecture for distributed streaming data processing, which was developed by the authors earlier. Prospects for the use of intelligent technologies in the allocation of resources for peripheral computing are also considered.

Despite the fact that recently there are many approaches to optimizing the allocation of resources in large information systems, research in this area continues.

3. The purpose and objectives of the study. The aim of the work is to optimize the allocation of resources in large information systems through a multi-agent approach.

4. The main part.

An information system is an organized set of elements that collects, processes, transmits, stores and provides data. An information system consists of people, equipment, processes, procedures, data and operations. This information system not only reflects the functioning of the object of management, but also influences it through government. It is a set of information processes to meet the information needs of different levels of decision making. The task of allocating system resources is a complex multi-extreme task. Modern information systems support the function of allocation and redistribution of resources, but we still need to look for new methods for optimal redistribution.

4.1. Allocation of resources in the framework of stationary tasks.

Let there be n orders and m types of resources. Consider one way to formalize the task of allocating resources between orders in order to maximize benefits. Denote r_i – the number of j-th resource, $j=\overline{1,m}$. We will assume that for each order $i=\overline{1,m}$ there is a function $c_i : R_+^m \to R_1$ that sets the possible profit when using $x_{i,1}, x_{i,2}, ..., x_{i,m}$ resources of the appropriate type. From a mathematical point of view, the task of resource allocation is to find a matrix of resource $X \in R^{nm}$ allocation that maximizes the functionality:

$$C(X) = \sum_{i=1}^{n} c_i\left(x_{i,1}, x_{i,2}, ..., x_{i,m}\right) \to \max \tag{1}$$

subject to restrictions on the total number of resources

$$\sum_{i=1}^{n} x_{ij} \le r_j,\ j = 1, 2, ..., m \tag{2}$$

and their positivity

$$x_{ij} \geq 0,\ i = 1, 2, ..., m. \tag{3}$$

The transport problem can be considered as some generalization of the problem of destination. Given a typical resource, which is extracted in *n* mines, and which is interested in m factories that want to get the resource in quantity $z_i,\ i = 1, 2, ..., m$. The matrix of costs of transportations of unit volume of a resource F in the size $m \times n$ with elements from is set R. The task is to minimize the cost of transporting resources, ie you need to find a matrix of resource allocation *X*, which would minimize the functionality with additional restrictions on the satisfaction of all orders:

$$\sum_{j=1}^{m} x_{ij} = z_i,\ i = 1, 2, ..., n \tag{4}$$

and meeting the conditions of limited and positive resources.

Conditions can be reduced to a general form by adding *m* rows at the beginning of the matrix A

$$\begin{cases} a_{ij} = 1,\ if\ \ i = 1, 2, ..., n,\ j = i, i+n, ..., i+n(m-1), \\ a_{ij} = 1,\ if\ \ i = 1, 2, ..., n,\ for\ everyone\ else\ \ j, \end{cases} \tag{5}$$

and $z_1, z_2, ..., z_n$ at the beginning of the vector R.

As well as the task of appointment, the transport problem can also be solved. A more complex example is the task of scheduling the use of school classrooms. Resources in this case are the audience along with the time interval of classes. Relevant time intervals are traditionally pre-arranged.

In fairly simple cases, this task can be reduced to solving the problem of coloring the graph. In solving this problem, genetic methods, randomized algorithms, linear programming, neural networks are quite common.

4.2. Allocation of resources within non-stationary tasks.

We consider the time factor *t*, which can be considered both discrete and continuous. The previously considered stationary case corresponds to one point in time. In the non-stationary case, there are important features of resources – resources can be wasted over time and be reproductive, their number is limited per unit time. It is worth noting that the resource can have both properties at the same time.

Let's denote by M_c та M_r sets of reproductive and spent resources, respectively. Let the set $r = \{r_j,\ j \in M_c\}$ sets the limitations of reproductive resources at the time t. For the spent resources we will in addition enter a set $\varphi = \{\varphi_j,\ j \in M_c\}$, showing the total number of these resources. In the inpatient case, there is no difference between reproductive materials and consumables, so resources and kits r, φ are the same. In the general case φ, the set of total resources spent may depend on time $\varphi(t)$, including both the possibility of replenishing resources and the possibility of losing them.

Orders have new characteristics: time of entry into the system t_i^{in}, critical acceptance time (rejection) t_i^{d}, order execution time t_i^{out}, $i = 1, 2, .., n$. Order profit function i, also becomes non-stationary, there is a dependence not only on the resources used, but also on the time of execution of orders. Denote $X(t)$ the set of resource allocation between orders at time *t*. For the non-stationary case with the final temporary set $0 \leq t \leq T < \infty$, the task of allocating resources between orders can be reformulated as follows:

$$C(X(.)) = \sum_{t=0}^{T} \sum_{i=1}^{n} c_i\left(t, x_{i,1}, x_{i,2}, ..., x_{i,m}\right) \to \max \tag{6}$$

in discrete time, or

$$C(X(.)) = \int_{t=0}^{T} \sum_{i=1}^{n} c_i \left(t, x_{i,1}, x_{i,2}, ..., x_{i,m} \right) \to \max \tag{7}$$

in continuous time, under the conditions of inalienability

$$x_{i,j}(t) \geq 0, i = 1, 2, ..., n,\ j = 1, 2, ..., m,\ 0 \leq t \leq T \tag{8}$$

restrictions on the total number of reproductive resources

$$\sum_{i=0}^{n} x_{i,j}(t) \leq r_j,\ j \in M_c,\ 0 \leq t \leq T \tag{9}$$

and additional constraints on resources expended

$$\sum_{i=0}^{n} \sum_{j=0}^{t} x_{i,j}(s)ds \leq \varphi_j(t),\ j \in M_r,\ 0 \leq t \leq T \tag{10}$$

in discrete time, or

$$\sum_{i=0}^{n} \int_{0}^{t} x_{i,j}(s)ds \leq \varphi_j(t),\ j \in M_r,\ 0 \leq t \leq T \tag{11}$$

in continuous time.

In many non-stationary cases, there are difficulties if the tasks (resources) come in real time, the parameters of the task are not known in advance and may change over time.

4.3. Allocation of resources in multi-agent systems.

In the case of resource allocation in multi-agent systems, their decentralization must be taken into account: not always every agent of such a system can interact with others. In our case, respectively, not every order can be available to each of the resources, which can be formally set by the following restrictions: $D \in M\left(n, m\right)$ – the adjacency matrix of the connection graph, $D_{ij} \in \{0,1\}$, then

$$x_{ij} \leq D_{ij} r_j \ . \tag{12}$$

In the non-stationary case, the network topology may change, so in the non-stationary case. In the non-stationary case, the network topology may change, so in the non-stationary case D_{ij} depends on time, and

$$x_{ij} \leq D_{ij}(t) r_j,\ \forall t. \tag{13}$$

Another feature of the decentralized approach is the fact that, generally speaking, agents are directly responsible for themselves and do not have complete information about the system, which changes the essence of the task: instead of finding a distribution, we build agent behavior to obtain this desired distribution.

4.4. Planning tasks.

Traditional planning theory considers the general problem of division of labor on computing devices. A fairly large class of planning tasks is included in the described task of resource allocation. The only type of resources in such tasks are computing resources. The following is an example of a typical planning task: there are m computing devices and n orders. Each order is known for: T_i – time of receipt of the order, V_i – order fulfillment fee and D_i – order term. If the order is executed between the time of receipt and the deadline, we receive the corresponding benefit. It is also known that the calculator i can fulfill the order j for an time r_{ij} (the order must be executed on one of the computers). Thus, formally, you need to maximize the following functionality:

$$c_i \coprod_{j=1}^{m} \left(\left[\int_{T_i}^{D_i} x_{i,j}(t)dt \right] \geq r_{j,i} \right) \cdot V_i \tag{13}$$

with CPU time limit:

$$\sum_{i=1}^{n} x_{i,j}(t) \leq 1,\ \forall t, j\ . \tag{14}$$

It is worth noting that often such tasks need to be solved in real time, ie we will learn about the order only when it arrives.

5. Discussion of the results. Management systems of groups of objects are actively developing at present, and the perspective direction of their development is development of technical decisions for use in them of tools of planning of the coordinated group actions of mobile devices at performance of the joint task. For the successful use of such systems, their functionality should, in addition to task planning, allow adjustments to existing plans for changing tasks in changing conditions, including responding to unforeseen situations by redistributing subtasks between individual objects of the group. Versatility and independence from the context of the task of the proposed solution methods will reduce the time for implementation and reduce the cost of their creation by reducing the stage of development of software solutions. Thus, in a short time it is possible to design and commission based on the use of multi-agent technologies for planning new-generation software and hardware systems that can interact and work in a group and applicable to a wide range of tasks in various fields.

6. Conclusions. Traditional planning theory considers the general problem of division of labor on computing devices. A fairly large class of planning tasks is included in the described task of resource allocation. The only type of resources in such tasks are computing resources. The article considers different approaches to the allocation of resources in large information systems. These approaches help to solve various applications in real time. In the case of resource allocation in multi-agent systems, their decentralization must be taken into account: agents are directly responsible for themselves and do not have complete information about the system, which changes the very essence of the task. Thus, the development of multi-agent models is possible, as there are software products that allow you to do so, because the functions of the agent modeling system, may not always be completely satisfied, there is.

The multi-agent scheduling methods used in the system can be used in real-time decentralized systems compared to the previously mentioned traditional methods. Their application provides management of planning and execution of tasks, they can be used to manage groups of objects consisting of a large number of devices and able to quickly process large-scale tasks.

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