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MULTIAGENT APPROACH FOR MANAGING THE INFORMATION SPACE OF CORPORATE SYSTEMS

The **subject matter** of the study is the integration and management of information resources of distributed computing corporate systems within the common information space. The **goal** of the study is to develop scientifically based models for supporting intelligent technologies for the integration and management of information resources of distributed computing systems. In accordance with the goal of the study, the article deals with the following **tasks**: to develop a formal-logical model of the information space, to study and formalize agent-oriented tasks, to select the model of a software agent, to substantiate the information technology aimed at effective information management in corporate systems. The following **results** were obtained: a formal model of the information space of a corporate information system was developed; the role and place of a user of the information system resources were determined; the concept of the task and the flow of user tasks in the information space were considered and formalized; the definition of a software agent, multi-agent space and a multi-agent space management system were suggested; the model of the frame structure of knowledge representation modified by the authors is proposed as a logical model of a software agent. **Conclusions.** The analysis of domestic and foreign sources showed that the study in the field of integration of information resources of distributed systems and building a unified information space does not fully meet the modern requirements of users and developers of application software. Existing solutions based on integration technologies do not allow heterogeneous information structures to be actually integrated. Basing on the study of the main business processes in information systems "user - information environment", a model of information multi-agent space of a computer system was developed and investigated. The main components of a multi-agent system were identified and basic entities were formally defined as a software agent and a multi-agent space. The agent-oriented approach to solving managerial problems and integrating information resources of distributed computing systems was formulated and substantiated.

Keywords: information system; database; data integration; intelligent systems; heterogeneous information structures; frame; software agent; multi-agent system; task flow.

Introduction

The modern level of social development has determined the information technology industry as a strategic direction where huge intellectual and financial resources are concentrated. Information and information management tools – software products of various functional purposes - acquired the status of information resources [1]. Information management, like other areas of computer science, is undergoing radical changes in a number of its aspects: in storage and access models, in the scale of designed systems, as well as in basic information technologies. A number of studies deal with the study of issues related to the modern presentation of information, information resources and information technologies. [2-6]. And nowadays the concept of information management is more and more extending to such an area as the information space. [7].

The information space includes everything that is connected with the storage and purposeful processing of information. Information resources and means of their processing (databases, files, protocols, classifiers, document standards, computers, network equipment, telecommunication facilities, etc.) lie on the basis of the information space. The information space is structured through information systems – interrelated sets of methods and means of collecting, accumulating and storing, searching and analyzing, distributing and presenting information [8]. Information resources are concentrated within information systems (IS).

Combining resources on the basis of the information and communication interaction of information systems brings them to the level of corporate information resources that are called Common Information Space (CIS). The CIS of a region, corporation, enterprise can be implemented by creating and maintaining the standard for the interaction between both information systems and individual applications.

The problem analysis and the review of the existing methods of solving the set task

At the present stage of development of computer-oriented methods and information management tools, the issues of building the common information space are of primary importance. Over the past ten years, computer technologies have gone far beyond local application and the worldwide computer network Internet has opened up new functionalities for users. At the same time, the integration level of information systems, namely the study and development of methods for constructing the information space, does not fully meet the requirements of users at the present stage. The amount of stored and processed information continues increasing, which emphasizes the necessity to move some processing functions of heterogeneous information to intelligent systems. Such systems should independently obtain information, process it autonomously, make decisions about its further promotion within the information space [9]. Initially, decision-making systems dealt with similar issues. These systems were developed in two directions.

The first one involves developing intelligent systems for analyzing the flow of information, identifying dependencies in this stream, compiling data. Such a system provides a user with information that has been analyzed and processed. The received information is usually accumulated in databases, databanks and, if necessary, one can get access to its resources for more thorough studying.

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The second direction involves applying artificial intelligence methods. Such a system analyzes the situation and then gives its recommendations on it. If necessary, a user can learn the results and make own decision. However, the user of an information or information management system needs the system to be able to affect the processes of processing and managing information within the information space autonomously.

The study is aimed at creating intelligent systems for integrating and managing information resources of distributed computing systems. Integration is considered as the management of heterogeneous information based on an intelligent intermediary system, which enables access to multi-format information contained in the developed structures - data files and databases. An intelligent system based on software agent technology can be used as an intermediary system. Studies in the field of agent-oriented technologies as an integral part of the tasks of distributed artificial intelligence, modern advances in the field of computer systems made it possible to identify this area as an independent rapidly developing field of research and applications [10].

The problems of intelligent agents and multi-agent systems have been formulated on the basis of studies in the sphere of the distributed artificial intelligence. Agent technologies can be applied to workflow management [11], network management, information retrieval, e-commerce, education [12], digital libraries and to a variety of other applications [13].

The development of a formal-logical model of the information space

The computing environment of a modern corporation, institution, office, as a rule, is a server, network equipment, local computers, office equipment for various purposes, applied, system and special software. All computing system resources – from user files, database structures, application programs to system components – are stored in files and files are stored in named directories. Such a technology of a computing system organization is conceptual and depend neither on the class of tasks solved by a user nor on the type of interaction between a server and a local computer. Thus, the computing environment is an invariant component of any information system and creates the information space [14].

The information space can be represented as an abstract algebraic system:

$$E = < O, S, \Omega > , \qquad (1)$$

where O is the objects of the information space; S is the interrelations among O objects; Ω is object manipulation operations in E environment.

The components of a modern computing system can be the model objects (1), these are files of all types, directories, logical and physical disks, personal computers $O = \left\{ o_n \middle| n = \overline{1, N_1} \right\}$. The relation $S = \left\{ s_n \middle| n = \overline{1, N_2} \right\}$ among the objects of the information space determines specific computer environment configuration E, oriented to a specific user or users, $G = \left\{ g_n \middle| n = \overline{1, N_3} \right\}$ is a set of users.

Depending on the goals set for a user and the computer environment, all actions are conducted on the basis of operations $\Omega = \left\{ q_n \middle| n = \overline{1, N_4} \right\}$. An example of a set of elementary operations $\Omega = \{ q_1, q_2, ...q_n \}$ can be such file manipulation operations in the information space as {<run>,<copy__from__to>,…..,<delete>}. All operations on objects at arbitrary times $t_1, t_2, ...t_m$, $t_{m+1} > t_m$ are initiated by the user g_n of the information space on the basis of the formalized plan of actions $z^*_{n1}(t_1), z^*_{n2}(t_2), ...z^*_{nm}(t_m)$ or unitary action $z^*_1(t)$.

Thus, the formalized task z_1 =<to copy file from___to____>, can be solved by the following operations q_1 =<copy__from__to>.

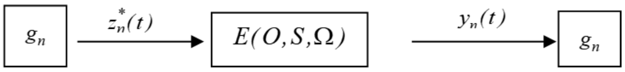

Fig. 1. The pattern of the user interaction with the information space

The pattern of the interaction *user – information space* is presented in fig.1.

The model of the user interaction with the information space can be presented as follows

$$y_n(t) = e_n(z_n(t)),\ i = \overline{1, N_3}, \qquad (2)$$

where $z_n(t)$ is the input impact on the information space made by the user $g_n \in G$; $y_n(t)$ is the response of the system E, that is configured for the user g_n and looks like e_n.

In the general case, $z_n(t)$ is an elementary task that the user $g_n \in G$ solves using the information system $E(O, S, \Omega)$.

Elementary tasks can be can be combined into functional tasks by combining elementary operations $q_l, q_2, ..., q_n$ into a sequence of interrelated operations of the algorithm $a_k = \{ q_l, q_2, ..., q_n \}$, $a_k \in \Lambda$, where Λ is a set of algorithms for solving functional problems. Depending on the structure and interrelation of tasks solved by the user, they can be combined into sequences or task flows. The task flow of the user $g_n \in G$ is called such a sequence, $P(y_n) = \{ y_{n1}, y_{n2}, ..., y_{nk} \}$ which meets the following conditions:

$$y_{nj}(t) = e_{nj}(z_{nj}(t)),\ n = \overline{1, N_3},\ j = \overline{1, K}. \qquad (3)$$

$$z_{nj}(t) = y_{nj+1}(t), \qquad (4)$$

where j is the ordinal number of the task of the n-th user.

Let us detail the meaning of constraints (3-4). The effect of restriction (3) is as follows. While working with the information system, a user has a plan of sequential or parallel operations (actions), for example, to copy

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unnecessary files to the "recycle bin", then start the anti-virus program, then open the database file and execute a SQL query. The meaning of constraint (4) is the following – the result of the previous task is an indispensable condition for starting the next task or tasks. A feature of the task flow technology lies in the fact that tasks can form both a sequential and an arbitrary sequential-parallel process for solving them. The main condition for grouping tasks into a stream is to coordinate adjacent tasks on input/output, while at intermediate stages, a task (in the general case) can be understood as a user action that does not require tools to support the computer system [15].

Let us consider a special case of the task flow, when to solve each task z_{nk}, there is an instrumental software package or software module $m_k \in M$, where M is a set of software modules that implement a set of tasks Z. In addition, the conditions for the coordination of tasks in a flow should be met. The first condition is the logical completion of the previous task and the beginning of the next one.

The second condition is the condition for data coordination at the intermediate stages of the solution: $y_{nj}(t) = z_{nj+1}(t)$, where the output data of the previous task are the input data for the following task. Then, the general solution of the task flow can be represented as a sequence of solving the task $z^*_{n1}(t), z^*_{n2}(t), ...z^*_{nj}(t)$, $i = \overline{1, N_3}$, $j = \overline{1, K}$.

The development and study of a software agent model on the frame basis

For the considered class of tasks, where the user is an "active element" to initialize their implementation and the data formats at the intermediate stages of the coordination coincide or the sequence of their solutions is strictly defined, the task of autonomous task (task flow) management can be formulated and solved basing on the technology of software agents.

Let us introduce the basic definitions.

Definition 1.

A software agent is an application that operates in the computer environment on the basis of the *condition-action* model and is used to perform the tasks of a user information support autonomously.

Definition 2.

A multi-agent space is an information space of a computer system where software agents, which are either autonomous or coordinated by a multi-agent space control system (MASCS), operates for the purposes of a user.

Definition 3.

A multi-agent space control system is a manager that designs, develops, implements, monitors and analyzes the operation of a system based on the technology of software agents.

Definition 4.

The technology of software agents is the principle of managing information resources of a distributed computing environment based on autonomous software applications (software agents).

For the formal definition of the concept of a multi-agent space, let us consider the model of the information space (1) and the model of the multi-agent space can be represented as:

$$E_p =< O_g, S_g, \Omega_g >. \qquad (5)$$

In this case, a set of objects of the information space can be represented as $O_g = O \cup A_g$, where A_g is a set of software agents.

A set of relations $S_g = S \cup S_a$, where S_a is a set of relations among the agents A_g and the objects of the O_g, and a set of relations $\Omega_g = \Omega \cup \Omega_a$, where Ω_a is a set of operations among the agents A_g and the objects of the information space O_g.

Let us consider a software agent as an abstract algebraic system. In this case, the concept of a software agent should involve a universal language for describing data and means of manipulating the entire range of types of information system data, from text files to database files. Such a hierarchical approach to building a software agent model is not rational for the following reasons. The basic file types and their structure (*.txt, *.xls and so on) have been developed, as a rule, for specialized software systems, thus *.doc files – for the text editor WORD, *.dbf files – for database control systems. In very rare exceptions these applications are closed algebraic systems.

Recently, the attention of researchers has been focused on the development of the concept of data type, taking into account the principle of hierarchical construction, without relating to initial or terminal algebras. The hierarchical data type is constructed on the basis of one or several primitive types (which, in turn, can be hierarchical) that are included in the original data type system. Each primitive type can be analyzed and implemented separately; the information about the types that can be constructed with it will not be used. On the other hand, the newly created type can be considered as a "black box", whose behaviour is evaluated in terms of primitive types.

Basing on the above, the concept of a software agent model as an algebraic system consisting of disjoint closed subsystems should be considered.

Statement. In the algebraic system $U_a =< A, \Omega >$, where $\Omega = \Omega_f \cup \Omega_p$, $\Omega_f = \{F_1, ...F_k\}$, $\Omega_p = \{\pi_1, ...\pi_m\}$, $A = \{A_1, A_2, ..., A_r\}$, the non-empty subset $A_1 \subseteq A$ is called closed if $\forall A_1 \exists < F_k, \pi_i >$, that is, A_1 is closed regarding each major operation F_k of this system. This means that the result of any major operation, performed on arbitrary elements of the set A_1, belongs to A_1 again. Let $F_k^{'}$ and $\pi_m^{'}$ designate operations and predicates, determined on A_1, whose values on A_1 correspond to the values of operations $F_k \in \Omega^{'}$ and predicates $\pi_m \in \Omega^{'}$. As a result, there is the algebraic

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system $U_{a1} = < A_1, \Omega' >$, which is a subsystem or a sub-model of the system U_a. The subsystem U_{a1} is uniquely determined by the set A_1 and, hence, instead of $U_{a1} = < A_1, \Omega' >$ $U_{a1} = < A_1, \Omega >$ can be used.

The above statement enables representing the model of the software agent as an abstract data type in terms of non-overlapping subtypes. One of the well-known structures of data representation and knowledge that satisfies the conceptual model of multi-agent space (5) is a frame. To implement the technology of interaction between a software agent and objects of the computer environment, the frame structure can be used as a model of a software agent. A software agent model can be represented by a frame. In the general case, such a model can be written as:

$$FR = \left\{ \begin{matrix} < R_1, C_{11}, C_{12}, ...C_{1m} >, ... < R_2, C_{21}, C_{22}, ... \\ ...C_{2m} >, < C_{km} > \end{matrix} \right\}, \quad (6)$$

where *FR* is the frame name; pair <*Ri*,*Ci*> is the i-th frame slot; *Ri*, is the slot name, *Ci* is the slot value.

Based on the frame (6), the model of the software agent can be implemented in terms of <objects>, <conditions>, <actions>, <priority>. The frame acts as a universal framework or a standard shell, into which functional modules-slots can be added to solve specific problems of information resources administration. Each slot can be formed from four attributes of basic types and perform the required operations with data. The slot in the model (6) is a logical structure for implementing specific tasks for a frame – a software agent.

Slots from the frame can be removed, add, change the functionality of the slot-task. However, the classic representation of a slot as a structure <name>, <meaning> cannot fully represent the requirements of the conceptual model of a software agent. Let us modify the slot structure and transform it as:

$$Slot = \langle U, D, dom, r_1, \theta, \Omega \rangle, \quad (7)$$

where U is a set of attribute names, D is a set of domains, dom is the display $U \Rightarrow D$, θ is a set that determines initial conditions and signs of actions in the task structure, Ω is a set of operations, and $\Omega = \{\Omega_1, \Omega_2, \Omega_3\}$, where Ω_1 is operations on slots-tuples, Ω_2 is operations on slot states, Ω_3 is operations on the values of typical attributes.

And $\Omega_3 = \{\Omega_{31}, \Omega_{32}\}$, where Ω_{31} is operations on the data of the same type, Ω_{32} is inter-type operations, r_i is the model-tuple of the i-th task of the agent,

$$r_i = \{\{R\}_{ij}, \Omega_i, V_i\}, \quad (8)$$

where $\{R\}_{ij}$ is a set of the states of the tuple r_i, V_l is a set of integrity constraints, $\Omega_{ij} \subset \Omega_2$ is a set of operations over $\{R\}_{ij}$.

In accordance with the basic requirements for the properties of software agents - the autonomy of operation and the ability to perform meaningful actions, let us consider an approach to building the model of the software agent behaviour basing on the concept "frame-slot" [16].

A slot in the mathematical model (7) can be represented as a logical model when the values of the attributes of the set при значениях атрибутов множества U are equal to $\{< OBG >, < ACT >, < CON >, < STA >\}$. Taking into consideration (8), the slot logical model can be considered as a 2D object, whose structure is shown in fig. 2.

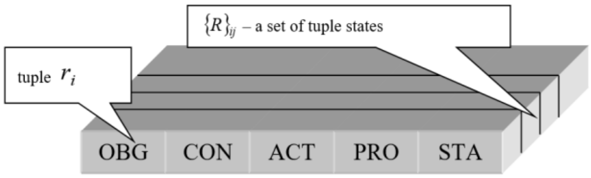

Fig. 2. 2D slot model

Example

The behaviour of a reflective software agent refers to the primitive type of behaviour of the "condition-action" type. When the condition specified by the [CON] attribute format is met, the action determined by the [ACT] specification is performed. The result of the task is reflected in the only tuple state, the sign of the execution is 1 if the action is completed successfully and 0 if the action is not completed successfully, and is stored in the value of the [STA] attribute. If a condition is specified for repeated actions, the result of the last execution will be displayed in the slot tuple state. The task for a reflective software agent is to copy an Itog.txt file, which is in C\PR directory, to C\ARXIV directory at 18.00 every day.

OBG: C\PR\Itog.txt	**CON:** Time=18-00	**ACT:** Copy from C\PR to C\ARXIV	**STA:**
Itog.txt	18-00	Copy from C\PR to C\ARXIV	1

Fig. 3. The example of a reflexive software agent

When analyzing the actions of a reflective software agent, one can only judge whether the last operation to copy the file was correctly performed at 18.00.

Conclusions

The analysis of domestic and foreign sources showed that the study in the field of integration of information resources of distributed systems and the construction of the common information space do not fully meet the modern requirements of users and developers of application software. Existing solutions based on integration technologies do not allow heterogeneous information structures to be actually integrated. Basing on the study of main business processes in information systems "user - information environment", the model of the information multi-agent space of a computer system was developed and investigated. The main components of a multi-agent system were identified and basic entities were formally defined as a program agent and a multi-agent space. The agent-oriented approach for solving management problems and integrating information resources of distributed computing systems and databases was formulated and substantiated.

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МУЛЬТИАГЕНТНИЙ ПІДХІД В ЗАДАЧАХ УПРАВЛІННЯ ІНФОРМАЦІЙНИХ ПРОСТОРОМ КОРПОРАТИВНИХ СИСТЕМ

Предметом дослідження є інтеграція і управління інформаційними ресурсами розподілених обчислювальних корпоративних систем в рамках єдиного інформаційного простору. Метою проведених досліджень є розробка науково-обгрунтованих

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моделей підтримки інтелектуальних технологій інтеграції і управління інформаційними ресурсами розподілених обчислювальних систем. Відповідно до поставленої мети досліджень у представленій статті розглядаються наступні **завдання**: розробка формально-логічної моделі інформаційного простору, дослідження і формалізація агентно-орієнтованих задач, вибір моделі програмного агента, обґрунтування інформаційної технології, спрямованої на ефективне управління інформацією в корпоративних системах. У статті отримані наступні **результати:** розроблена формальна модель інформаційного простору корпоративної інформаційної системи; визначені роль і місце користувача інформаційними ресурсами інформаційної системи; розглянуто і формалізовано поняття завдання та потоку завдань користувача в інформаційному просторі; дано визначення програмного агента, мультиагентного простору і системи управління мультиагентним простором; в якості логічної моделі програмного агента запропонована модифікована авторами модель фреймової структури представлення знань; **висновок:** аналіз вітчизняних і зарубіжних джерел показав, що дослідження в області інтеграції інформаційних ресурсів розподілених систем і побудова єдиного інформаційного простору, не в повній мірі відповідають сучасним вимогам користувачів і розробників прикладного програмного забезпечення. Існуючі рішення на основі інтеграційних технологій не дозволяють здійснити реальну інтеграцію гетерогенних інформаційних структур. На підставі дослідження основних бізнес процесів в інформаційних системах "користувач - інформаційне середовище", розроблена і досліджена модель інформаційного мультиагентного простору обчислювальної системи. Виділено основні компоненти мультиагентної системи і дано формальні визначення базових сутностей: програмному агенту, мультиагентному простору. Сформульовано та обґрунтовано агентно-орієнтований підхід до вирішення завдань управління і інтеграції інформаційних ресурсів розподілених обчислювальних систем.

Ключові слова: інформаційна система; база даних; інтеграція даних; інтелектуальні системи; гетерогенні інформаційні структури; фрейм; програмний агент; мультиагентна система; потік завдань.

МУЛЬТИАГЕНТНЫЙ ПОДХОД В ЗАДАЧАХ УПРАВЛЕНИЯ ИНФОРМАЦИОННЫМ ПРОСТРАНСТВОМ КОРПОРАТИВНЫХ СИСТЕМ

Предметом исследования является интеграция и управление информационными ресурсами распределенных вычислительных корпоративных систем в рамках единого информационного пространства. **Целью проводимых** исследований является разработка научно-обоснованных моделей поддержки интеллектуальных технологий интеграции и управления информационными ресурсами распределенных вычислительных систем. В соответствии с поставленной целью исследований в представленной статье рассматриваются следующие **задачи:** разработка формально-логической модели информационного пространства, исследование и формализация агентно-ориентированных задач, выбор модели программного агента, обоснование информационной технологии, направленной на эффективное управление информацией в корпоративных системах. В рассматриваемой статье получены следующие **результаты:** разработана формальная модель информационного пространства корпоративной информационной системы; определены роль и место пользователя информационными ресурсами информационной системы; рассмотрено и формализовано понятие задачи и потока задач пользователя в информационном пространстве; дано определение программного агента, мультиагентного пространства и системы управления мультиагентным пространством; в качестве логической модели программного агента предложена модифицированная авторами модель фреймовой структуры представления знаний; **вывод:** анализ отечественных и зарубежных источников показал, что исследования в области интеграции информационных ресурсов распределенных систем и построение единого информационного пространства, не в полной мере соответствуют современным требованиям пользователей и разработчиков прикладного программного обеспечения. Существующие решения на основе интеграционных технологий не позволяют осуществить реальную интеграцию гетерогенных информационных структур. На основании исследования основных бизнес процессов в информационных системах "пользователь – информационная среда", разработана и исследована модель информационного мультиагентного пространства вычислительной системы. Выделены основные компоненты мультиагентной системы и даны формальные определения базовым сущностям: программному агенту, мультиагентному пространству. Сформулирован и обоснован агентно-ориентрованный подход к решению задач управления и интеграции информационных ресурсов распределенных вычислительных систем.

Ключевые слова: информационная система; база данных; интеграция данных; интеллектуальные системы; гетерогенные информационные структуры; фрейм; программный агент; мультиагентная система; поток задач.