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**METHODS OF DISTRIBUTION OF DATA PROCESSING SYSTEMS
TO THE NODES OF COMPUTING SYSTEMS**

Abstract. A new class of discrete programming problems - block-symmetric problems is considered in this paper. General formulation and solution of block-symmetric problems of discrete programming are presented.

The features and properties of this class of problems are given. The formulation and solution of the problem of optimal allocation of program modules and database arrays to the nodes of computing systems of a given topology is considered.

Key words: model, method, algorithm, variable, block-symmetric problem, discrete programming.

Introduction. Large-scale development and implementation of information systems is carried out on the basis of computer networks on which data processing systems are operated.

By data processing systems we mean a set of application software for the implementation of various applications and associated database arrays.

With the increase in the number of applications, there arises a problem of the optimal allocation of the set of application software and database arrays to the nodes of the computing system of a given topology. This allocation problem also arises when a node of computing system and communication channels between nodes fail.

The existing optimization methods for solving this problem are not effective because of the small dimensionality of the problems being solved.

Therefore, there is a need to develop new productions, models and methods for solving these problems.

One of the approaches is the application of a new class of problems of setting and solving discrete programming problems for block-symmetric problems.

1. General statement of block-symmetric discrete programming problems. The problems of discrete programming are widely used in the formulation and solution of applied scientific and technical problems.

At the same time, this section of applied mathematics is conservative for a number of reasons. The main ones being the exponential computational complexity of traditional statements of discrete programming problems, the difficulty of constructing effective algorithms for solving problems, the inadequacy of traditional problem statements for new applied problems that arise in various fields of science and technology, in particular in the field of information technology.

Therefore, one of the research areas is the development of new classes of discrete programming problems that most fully meet the modern requirements of setting and solving applied problems.

A number of applied problems: the design of modular software and database arrays of information systems, the distribution of program modules and database arrays to the nodes of computing networks, the choice of projects in conditions of limited resources can be formulated in the form of a new class of tasks -

block-symmetric models of discrete programming. Unlike traditional models, models of this class make it possible to formulate problems with several types of variables of different nature, to decompose complex problems into blocks with a single objective function and to develop efficient algorithms having polynomial computational complexity [1,2].

Let us consider the general formulation and solution of block-symmetric problems of discrete programming.

Problem statement. Let the set of objects $A = \{a_i; i = \overline{1, I}\}$ and the set of objects $B = \{b_j; j = \overline{1, J}\}$ are given with elements of different types, and also the interrelations between the elements of these sets that are defined by matrix $W = \|\omega_{ij}\|, i = \overline{1, I}, j = \overline{1, J}$, whose elements are integer or Boolean. It is necessary to combine the elements of the set A into disjoint subsets $A_n, n = \overline{1, N}$, and the elements of the subset B to disjoint subsets $B_m, m = \overline{1, M}$, in such a way as to deliver the extreme of the objective function $F(A_n, B_m)$.

For a formal formulation of the problem, we introduce the following variables. Let $X = \|x_{in}\|, i = \overline{1, I}; n = \overline{1, N}$ be a Boolean matrix, where $x_{in} = 1$ if the i -th element is distributed to the n -th group and $x_{in} = 0$ otherwise. Similarly, $Y = \|y_{jm}\|, j = \overline{1, J}; m = \overline{1, M}$, where $y_{jm} = 1$, if the j -th element is distributed to the m -th group and $y_{jm} = 0$ otherwise. In the general case of a matrix, the variables X and Y can be integer.

We define on the set $A \times B$ the function $F(X, Y)$, depending on the distribution of the elements of the sets A and B in the subsets A_n and B_m . Correspondingly, on the set of the A-function $\varphi_k(X), k = \overline{1, K}$, and on the set B - the functions $\psi_s(Y), s = \overline{1, S}$, defining constraints on the sets A and B.

The block-symmetric discrete programming problem is formulated as follows:

$$F(X, Y) \rightarrow \text{extr} \quad (1.1)$$

under constraints

$$\varphi_k(X) \leq \varphi_{ko}, k = \overline{1, K} \quad (1.2)$$

$$\psi_s(Y) \leq \psi_{so}, s = \overline{1, S} \quad (1.3)$$

In the set of constraints (1.2) and (1.3), depending on the statements of problems, the signs of the inequalities can be reversed.

In general, two-index matrices - the variables X and Y and a given matrix W can be integer-valued.

Consider the problem under the condition that the variables X, Y and W are Boolean matrices. As functions $F(X, Y)$, often use a function of the form $F(Z)$, where

$$Z = XWY \quad (1.4)$$

Consider the expression (1.4), which is the product of the matrices of the variables X and Y and the given matrix Z on which the objective function is defined. Unlike traditional statements of discrete programming problems, in this formulation there are two types of variables X and Y, the variables X and Y are symmetric with respect to the given matrix W.

In the problem (1.1) - (1.3) one can select the set of constraints of the form (1.2.) that depend on the variable X, and the set of constraints of the form (1.3) that depend on the variable Y.

A functional of the form $F(X, Y)$ can be represented as follows:

$$F(p(X), g(Y)) \rightarrow \text{extr} \quad (1.5)$$

$$p(X) \rightarrow \text{extr} \quad (1.6)$$

$$\varphi_k(x) \leq \varphi_{ko}, k = \overline{1, K} \quad (1.7)$$

$$g(Y) \rightarrow \text{extr} \quad (1.8)$$

$$\psi_s(Y) \leq \psi_{so}, s = \overline{1, S} \quad (1.9)$$

In the formulation of the problem (1.5) - (1.9), we single out a block of functions (1.6) - (1.7) depending only on the variable X , and a block of functions (1.8) - (1.9) depending only on the variable Y , united by a single functional of the form (1.5). Note that in a number of problem statements there can be a constraint block of the form

$$f_r(X, Y) \leq f_{r0}, r = \overline{1, R} \quad (1.10)$$

depending only on the variables X and Y .

In this case, we can select a block of the objective functional of the form (1.5), (1.10).

Thus, the problem (1.2.5-1.2.10) is called the block-symmetric discrete programming problem.

In a number of problem statements, the functional $F(X, Y)$ can be represented as a function vector. In this case, a multicriterial block-symmetric discrete programming problem is formulated.

Consider the features and properties of block-symmetric problems.

2. Analysis of features and properties of block-symmetric models. Basic algorithm for solving block-symmetric problems. Analysis of the general statement of the block-symmetric problem showed that the model of this class differs from the known models of discrete programming.

Consider the problem under the condition that the variables X , Y and W are Boolean matrices. As functions $F(X, Y)$, often use a function of the form $F(Z)$, where

$$Z = XWY \quad (2.1)$$

Expression (2.1) is the product of the matrices of the variables X and Y and a given matrix W on which the objective function is defined. Unlike traditional statements of discrete programming problems, in this formulation there are two types of variables X and Y , the variables X and Y are symmetric with respect to the given matrix W .

In the problem (1.1) - (1.3) one can select a set of constraints of the form (1.2) that depend on the variable X , and the set of constraints of the form (1.3) that depend on the variable Y .

We consider the expression (2.1.). It follows from this that the variables X and Y are symmetric with respect to the given matrix W , and the function (2.1) can be defined from left to right, and vice versa, i.e.

$$Z = XWY = YWX \quad (2.2)$$

On the basis of the general formulation, we define the basic properties of the formulated class of problems that distinguish it from the traditional statements of problems of discrete programming.

Property 1. The presence of two types of variables X and Y of different types, represented in the form of Boolean matrices, which are defined on the given matrix W .

Property 2. The blocking of the problem consists in isolating in the formulation of individual blocks functions of the form (1.2) and (1.3), depending on the corresponding variable X and Y .

Property 3. The symmetry of the problem consists in the possibility of computing (2.1) both in the forward and backward directions.

The solution of the problem. Analysis of the features and properties of the formulated problem allows us to propose effective algorithms for solving this class of problems. Consider the solution of block-symmetric discrete programming problems, provided that X , Y and W are Boolean matrices. It is easy to prove the following statement.

Statement. The distribution of the elements of the set A to the disjoint subsets A_n corresponds to the logical addition of the rows of the matrix W , $i \in n$, and the distribution of the elements of the set B with respect to disjoint subsets of B_m is the logical addition of the columns of the matrix W , $j \in m$. The results of this statement allow us to simply calculate the estimates and directions of the solution search for the development of effective algorithms.

We introduce the concepts of the basis for the solution of the problem. A basis is a predefined composition of the elements of the subset A_n and B_m .

In the matrix W the basis is found as a certain submatrix Z whose elements are defined. This submatrix can always be determined in the upper left corner by rearranging the row and column numbers

of the matrix and their renumbering. Such a representation simplifies the procedure for calculating estimates and determining the direction of the search for a solution.

To solve the block-symmetric discrete programming problem under the condition that, X , Y and W are Boolean matrices, an effective scheme for solving the problem is developed and proposed. The solution search scheme consists of the following main steps [3]:

1. In the Boolean matrix W , we select the matrix $Z = \|Z_{nm}\|$, $n = \overline{1, N}$; $m = \overline{1, M}$ and define it as the basis for the solution of the problem.

2. Define the matrix $D = \|d_{i^1 n}\|$, $i^1 = \overline{n+1, I}$; $n = \overline{1, N}$ of the direction of the search for the solution X by the logical addition of non-linear rows of the matrix W with rows basis and calculate the values of the estimates only for the positions of the basis.

3. In accordance with the estimates obtained, we realize the distribution of the elements of the set A with respect to the subsets A_n . As a result, we fix the solution X and the intermediate matrix $\Pi = \|\pi_{nj}\|$, $n = \overline{1, N}$, $j = \overline{1, J}$.

4. Define the matrix $D = \|d_{j^1 m}\|$, $j^1 = \overline{m+1, I}$; $m = \overline{1, M}$ of the direction of finding the solution Y by the logical addition of the non-spacing columns of the intermediate matrix $\Pi = \|\pi_{nj}\|$ with columns of the basis and calculate the values of the estimates only for the positions of the basis of the matrix Π .

5. In accordance with the estimates obtained for the matrix Π , we partition the elements of the set B with respect to the subset B_m . As a result, we fix the solution Y and the target matrix Z on which the value of the objective function $F(Z)$ is determined.

It should be noted that the search for the solution of the problem can be carried out both in the forward direction according to the scheme $DX \tilde{D}Y$, and in the reverse direction according to the scheme $\tilde{D}YDX$.

Thus, the basic model of a new class of problems - block - symmetric discrete programming problems is developed. In the future, we will consider the application of this model to solving applied problems in the design of information systems.

3. Development of methods for distributing application software modules and database arrays to nodes of computer systems. Designing information systems is a multi-stage and labor-intensive process and depends on the scale and class of the system.

The result of the design is a variety of applied data processing and control tasks, application programs and a database for the implementation of functional tasks. At the same time, one of the stages is the task of distributing tasks, program modules and a database on nodes of computer systems.

Depending on the purpose and characteristics of computing systems (local, corporate, global), the setting of tasks can also change. For example, in the process of designing information systems based on local computer networks of a homogeneous structure, it becomes necessary to distribute software modules and a database to nodes of computer systems in such a way as to minimize the number (time) of data arrays transmitted between nodes of the network. In a number of cases, it is necessary, with the given structure of the local network, to determine user functions by optimal distribution of program modules and database arrays. There are also tasks of redistribution of software and information resources in solving new tasks, various modifications of software systems, as well as damage to data transmission channels.

The developed models can be used in the process of distributing the application software and the database to the nodes of a computational system of a given structure, the synthesis of the structure (topology) of the computing system (CS) in conditions when the CS nodes and information resources (program modules and interrelated database arrays) are given.

The dynamic development of enterprises and firms in a highly competitive environment necessitates the introduction of information systems of various classes and purposes. At the same time, radical or evolutionary changes in the structure of enterprises (modernization, new technological process, commissioning of new capacities, etc.) invariably affect the information systems. The composition and number of information resources, the systems structure, the distribution of functional tasks and application programs to the nodes of the system are changing. CS nodes are remote computer systems of computing networks or points intended for data processing.

In the design process, the composition and number of application programs, the number and composition of the database, the purpose and number of nodes of the systems can change, which leads to a redesign of the structure of an operational information system.

Problem statement. Let us consider the problem of distributing software modules and database arrays to the nodes of the computer network. Let $A = \{a_i; i = \overline{1, I}\}$, - a set of applied programs for solving the functional problems of information systems. $\beta = \{b_j; j = \overline{1, J}\}$ - a set of database arrays (database fragments) used in the solution of applied problems. The matrix $W = \|\omega_{ij}\|$, ($\omega_{ij} = 1$, if the j -th database array is used to solve the i -th problem, otherwise $\omega_{ij} = 0$,) reflects the use of database arrays for solving application problems. The structure of a computer system or complex is specified by the matrix $G = \|g_{mn}\|$, $m, n = \overline{1, M}$, where $g_{mn} = 1$, if there is a data transfer channel between nodes m and n , $g_{mn} = 0$, if there is no communication channel between the nodes m and n .

It is necessary to distribute application programs and database arrays to nodes of the computer system in order to minimize the total number of transmitted arrays through communication channels under technological limitations. For the mathematical formulation of the problem, we introduce the following variables

$$x_{mi} = \begin{cases} 1, & \text{if } i\text{-th applied program is distributed in } m\text{-th network node;} \\ 0, & \text{otherwise} \end{cases}$$

$$y_{jn} = \begin{cases} 1, & \text{if } j\text{-th database array is distributed in } n\text{-th network node;} \\ 0, & \text{otherwise} \end{cases}$$

We also introduce auxiliary variables in the form:

$$a_{mj} = \begin{cases} 1, & \text{if } \sum_{i=1}^I x_{mi} \omega_{ij} \geq 1 \\ 0, & \text{if } \sum_{i=1}^I x_{mi} \omega_{ij} = 0 \end{cases} \quad (3.1)$$

The variable α_{mj} reflects the need to read the j -th database array by the m -th network node.

$$\beta_{in} = \begin{cases} 1, & \text{if } \sum_{j=1}^J \omega_{ij} y_{jn} \geq 1 \\ 0, & \text{if } \sum_{j=1}^J \omega_{ij} y_{jn} = 0 \end{cases} \quad (3.2)$$

The meaning of the variable β_{in} is that if the database array is located in the n -th node and it is needed to solve the i -th problem, the latter uses the n -th network node to read the database arrays.

We also define the derived variable

$$z_{mn} = \begin{cases} 1, & \text{if } \sum_{i=1}^I \sum_{j=1}^J a_{mj} \omega_{ij} g_{mn} \beta_{in} \geq 1 \\ 0, & \text{if } \sum_{i=1}^I \sum_{j=1}^J a_{mj} \omega_{ij} g_{mn} \beta_{in} = 0 \end{cases} \quad (3.3)$$

A variable z_{mn} reflects the transfer of data between m -th and the n -th nodes of the network.

The total number of transmission over the communication channels of the necessary data during the exchange of information is determined in the form

$$P = \sum_{m=1}^M \sum_{n=m+1}^M z_{mn} \quad (3.4)$$

We also introduce the following notation t_i - for the processing time of the i -th application program for the case of the same node performance in the implementation of programs, θ_{mi} - the processing time of the i -th application program in the m -th node of the computer network for the case of different node

performance, τ_{mj} – time of transfer of j -th array of data to a m -th node, V_i – the amount of memory occupied by the i -th application program, q_{mj} – the amount of j -th database that is sent to the m -th node.

The task of optimal allocation of software and information resources is formulated as follows

$$\sum_{m=1}^M \sum_{n=m+1}^M \sum_{i=1}^I \sum_{j=1}^J x_{mi} \omega_{ij} g_{mn} y_{jn} \rightarrow \min \quad (3.5)$$

subject to restrictions on:

duplication of tasks in nodes of computer networks

$$\sum_{m=1}^M x_{mi} = 1; \quad i = \overline{1, I}; \quad (3.6)$$

duplication of database arrays in nodes of computer networks

$$\sum_{n=1}^M y_{jn} = 1, \quad j = \overline{1, J}; \quad (3.7)$$

processing time of application programs and transfer of database arrays in the node of the computer network.

$$\sum_{i=1}^I t_i x_{mi} + \sum_{j=1}^J \tau_{mj} \alpha_{mj} \leq T_m, \quad m = \overline{1, M} \quad (3.8)$$

The amount of memory occupied by application programs and arrays of the database in the node of the computer network

$$\sum_{i=1}^I v_i x_{mi} + \sum_{j=1}^J q_{mj} \alpha_{mj} \leq V_m; \quad m = \overline{1, M} \quad (3.9)$$

and constraints of the form (1) - (4).

The problem (3.5) - (3.9) and (3.1) - (3.4) belongs to the class of block-symmetric problems of discrete programming [3].

To solve the formulated problem, an effective algorithm of iterative mappings is proposed [4].

Algorithm for solving the problem. 1. In the Boolean matrix, we select the submatrix $Z = \|Z_{ij}\|$, $i = \overline{1, N}$, $j = \overline{1, M}$ and define it as the basis for the solution of the problem.

The basis is defined in the form of a square matrix of the number of rows and columns, which is equal to the number of nodes of computing systems.

2. Define the matrix $D = \|d_{mi}\|$, $i = \overline{1, I}$, $m = \overline{1, M}$ directions of the solution search x by logical addition of the non-linear rows of the matrix W with the rows of the basis and calculate the values of the estimates only for the positions of the basis.

3. In accordance with the estimates obtained, we can distribute the elements of the set A over sets A_N . As a result, we fix the solution X and the intermediate matrix $\Pi = \|\pi_{mi}\|$, $m = \overline{1, M}$, $i = \overline{1, I}$.

4. Define the matrix $D = \|d_{j\backslash m}\|$, $j = \overline{1, J}$, $n = \overline{1, M}$, directions of the solution search Y by logical addition of the non-basis columns of the intermediate matrix $\Pi = \|\pi_{mi}\|$ with the columns of the basis and calculate the values of the estimates only from the positions of the Π basis of the matrix.

5. In accordance with the obtained estimates of the matrix Π we distribute the elements of the set B over the set B_m . As a result, we fix the solution Y and the target matrix Z on which the value of the objective function $P(Z)$ is determined.

The results of computational experiments showed high efficiency of the developed algorithm.

Conclusion. One of the actual tasks in the design and operation of information systems of various classes and purposes is the optimal distribution of data processing systems to the nodes of computing systems.

The problem of the optimal distribution of program modules and database arrays to the nodes of computing systems of a given topology was formulated and solved on the basis of the block-symmetric approach.

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КОМПЬЮТЕР ЖҮЙЕСІНІҢ ЖОЛ ТОРАБЫ (ТҮЙІНДЕРІ) АРҚЫЛЫ ӨТЕТІН ДЕРЕКТЕР ҚОРЫН ӨНДЕУ ЖҮЙЕСІН ТАРАТУ ӘДІСТЕРІ

Аннотация. Берілген жұмыста дискретті бағдарламалаудың жаңа классы – блок-симметриялық әдісі қарастырылған, оның жалпы тұжырымдамасы (қойылымы) жасалып, оны шешу жолы келтірілген. Бұл әдістің ерекше мүмкіндіктері мен қасиеттері көрсетілген.

Компьютер желісінің берілген желі топологиясының жол торабы (түйіні) арқылы өтетін деректер қорының массивін және бағдарламалық модульдерін желі арқылы таратудың оңтайлы әдісі қарастырылып, есептің қойылымы жасалған.

Түйін сөздер: модель, әдіс, алгоритм, айнымалы, блок-симметриялық мәселе, дискретті бағдарламалау.

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МЕТОДЫ РАСПРЕДЕЛЕНИЯ СИСТЕМ ОБРАБОТКИ ДАННЫХ ПО УЗЛАМ ВЫЧИСЛИТЕЛЬНЫХ СИСТЕМ

Аннотация. В работе рассматривается новый класс задач дискретного программирования – блочно-симметричные задачи. Приведена общая постановка и решение блочно-симметричных задач дискретного программирования.

Приведены особенности и свойства этого класса задач. Рассматривается постановка и решение задачи оптимального распределения программных модулей и массивов базы данных по узлам вычислительных систем заданной топологии.

Ключевые слова: модель, метод, алгоритм, переменная, блочно-симметричная задача, дискретное программирование.

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