

Analytical Processing of Infological Models of Applied Tasks at Design of Information-Active Systems

Olga Novoselova*, and Anton Ruzheynikov

Department of information technologies and computing systems, Institute of information technology, Moscow State University of Technology "STANKIN", RU-127055 Moscow, Russia

Abstract. The article describes the concept of the methodology of intellectual labor automation, a formal description of the infological model (ILM) at the object level, and also a description of the analytical processing of ILM. The infological model is a project of an information-active system for a computing environment, independent of software and hardware tools and implementation environments. The infological model describes the static, dynamic and functional components and their linkage. The elements of the static component (the infological structure) are structural units such as "information module", "information entity" and "information attribute". The dynamic component reflects the system of subject accesses to the infological structure. The functional component reflects the system of subject manipulations, which describes the algorithm for performing a class of applied tasks for the computing environment. The main stage of the analytical processing of infological models is the restructuring of their functional components. The method and technique of descriptions restructuring of the system of subject manipulations at the level of structural units of the "information attribute-5" type were developed. The method allows providing reduction of time and space expenses in the computing environment for the performance of the algorithm for solving a class of applied tasks at the design stage of information-active systems.

1 Introduction

The process of modeling information-active, automated, informational and other systems involves the formation of representations of various structures such as those of information and data, structure of the algorithm and their interactions. Currently, many methods and methodologies are known that allow the formation of task models and system designs. One of them is the methodology of intellectual labor automation (MAIL). [1]

The methodology of intellectual labor automation, developed at the Moscow State University of Technology "STANKIN", offers an industrial method of automated systems creation and determines the necessary and sufficient set of models that allows stage-by-stage imaging both the process of solving the problem and the project of an information-active system (IAS). When designing an information-active (automated) system, initial, conceptual, infological and datalogical models are formed. The initial model reflects the process of solving a subject problem by an expert. The conceptual model shows the structure of a domain knowledge system. The infological model is a project or "structure" of an information-active (automated) system, which is invariant to the program and technical environment and implementation tools. A datalogical model is a project or "technology model" that takes into account the implementation platform. Schematically, the

methodology of intellectual labor automation (MAIL) is presented in Figure 1. [1-3]

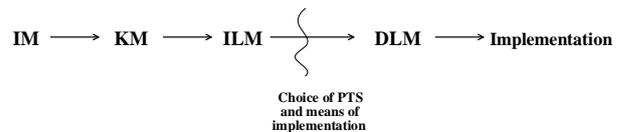


Fig. 1. Methodology of automation of intellectual work, where IM is the initial model, CM - conceptual model, ILM - infological model, DLM - datalogical model, PTS - software and hardware environment

Each model includes the description of informational or static, functional or/and dynamic components, a model in general. Informational (or static) component describes structure of static elements of the model. A functional component is an algorithm of the operations performed within a specific task. A dynamic component describes the structure of restrictions for static structure and accesses to it. The model in general defines coordination of functional or/and dynamic and informational or static components. At the same time, it includes the following components: for the initial model – functional and informational, for the conceptual model – dynamic and static, and for the infological model – functional, dynamic and static.

Each model includes the description of informational or static, functional or/and dynamic components, a model in general. The description of each component is given in the form of special diagrams and specifications.

* Corresponding author: olga.n10@yandex.ru

2 Infological model (ILM)

The purpose of the infological model is to organize and present information and data and the logic of their processing in a computing environment when designing information-active (automated) systems. The model is invariant to the program and technical environment and implementation tools, which allows you to implement a once developed project on various platforms without spending on the initial stages of problem modeling. [1]

The static structure of infological model (infological structure) describes the information structure of a subject task, which is organized as a multilevel structure. Each level is revealed by a set of named information modules (the module is an analogue of a database), consisting of a set of named information entities (an entity is an analogue of a relation). Each of the named informational entities includes a set of named informational attributes. A static structure consists of elements, binary and ternary relations established between elements, derived structures - schemes, binary and ternary relations established between schemes.

The dynamic structure (system of subject accesses) ensures the execution of information actions for writing and reading data necessary for the implementation of functional procedures on the formed information structure. It includes descriptions of subject accesses systems of the 1st and 2nd kind.

The functional structure (system of subject manipulations) is a set of interconnected functional procedures (computational, search, dialogue) for data processing. The subject manipulations system of the 1st kind determines the restrictions for a functional operation - a set of structural units of the "information module-5" type. The subject manipulations system of the second kind defines restrictions on the same structural units of the "information attribute-5" type, taking into account their "family tree" in the infological structure - the structure of location in the schemes.

The description of functional, dynamic and static structures in the formation of the infological model is performed in graphical form (diagrams) and in tabular form (specifications).

Visual notation for the subject manipulations system includes a set of elements (blocks and arrows); structures of these elements: sequence, iteration, alternative, cycle, switch; rules for building diagrams and models from elements and structures. The composition and structure of the diagrams is fixed in the specifications. The 1st kind of subject manipulations system means the use of information only from the level of structural units of the "information attribute-5" type to performing actions (subject manipulations) when executing an algorithm.

The infological model of the object level for the n-th applied task can be formally described as a set of structures and their linkages:

$$ILP2(n) = \langle L2(n), DE2(n), ZJ2(n), QI2(n), R_2^{IP}(n) \rangle \quad (1)$$

Structural units are divided into types: information module, information entity, information attribute.

$$L2(n) \equiv C(n), C(n) = \bigcup_p C^p(n),$$

$$C^p(n) = \bigcup_i C_i^p(n), C_i^p(n) \cap C_j^p(n) = \emptyset, \quad (2)$$

$$C_i^p(n) \subset C(n), C_i^p(n) = \{c_{il}^p\},$$

where $C_i^p(n) \equiv C_i^1(n) - i$ - a subset of structural units of the "information module" type,

$C_j^q(n) \equiv C_j^2(n) - j$ - a subset of structural units of the "information entity" type,

$C_k^r(n) \equiv C_k^3(n) - k$ - a subset of structural units of the "information attribute" type.

The set of static relations $DE2(n)$ can be represented:

$$DE2(n) = \langle D2(n), E2(n), \overline{E2}(n), De2(n) \rangle, \quad (3)$$

where $D2(n)$ - multitude of binary relations,

$E2(n)$ - multitude of ternary relations on structural units,

$\overline{E2}(n)$ - multitude of schemes of structural units,

$De2(n)$ - multitude of binary relations on schemes of structural units.

$$D2(n) \subset C(n) \times C(n). \quad (4)$$

$$E2(n) \subset C(n) \times C(n) \times C(n). \quad (5)$$

Multitude $E2(n)$ can be represented as a collection of subsets of a certain type:

$$E2(n) = \{EC_i^p(n) C_j^q(n) C_k^r(n)\}. \quad (6)$$

Under the scheme of structural units for subject manipulations we will understand the multitude of elementary schemes (elementary scheme - e_{iljmn}^2 is determined by the ternary relation of structural units), defined by:

- common structural units of «module» and «entity» type;

- non-repetitive structural units «attribute» type.

Formally, this is represented in the form

$$\overline{e_{iljm}^2} = \{e_{iljmn}^2, \dots, e_{iljmq}^2\}. \quad (7)$$

Then the scheme of structural units or derived structures is defined as follows:

$$\overline{e_{iljm}^2} = \{\overline{e_{iljmn}^2}\}. \quad (8)$$

Then the multitude of schemes of structural units for a subject task is defined as follows:

$$\overline{E2}(n) = \bigcup_{il} \overline{E2_{il}(n)}, \quad (9)$$

$$\overline{E2_{il}}(n) \subset \overline{E2}(n), \overline{E2_{il}}(n) = \{e_{ilm}^2\}.$$

Binary relations can be established between the schemes of structural units:

$$De2(n) \subset \overline{E2}(n) \times \overline{E2}(n). \quad (10)$$

Multitude $De2(n)$ can be represented as a set of subsets of a certain kind:

$$De2(n) = \{L\overline{E2_{il}}(n), L\overline{E2_{il}}(n)\overline{E2_{iq}}(n), \\ L\overline{E2_{iq}}(n)/\overline{E2_{il}}(n), L\overline{E2_{il}}(n)\overline{E2_{kn}}(n), \\ L\overline{E2_{kn}}(n)L\overline{E2_{kr}}(n)/L\overline{E2_{il}}(n)\}.$$

Binary relations on the schemes of structural units at the object level reflect the procedure of "deployment" (scaling) of sign representations.

The functional relations $ZJ2(n)$ include two types of restrictions - systems of object manipulations of the first $X2(n)$ and second $J2(n)$ kind:

$$ZJ2(n) = \langle Z2(n), J2(n) \rangle \quad (12)$$

$$Z2(n) = (X2(n), QX2(n)), \quad (13)$$

where $X2(n)$ - the multitude of subject manipulations of the 1st kind and $QX2(n)$ - multitude of binary relations between subject manipulations of the 1st kind.

$$X2(n) = \bigcup_p X2_p(n), X2_p(n) = \{x_{ps}\}. \quad (14)$$

The multitude of subject manipulations is divided into subsets of different levels decomposition:

$$QX2(n) \subset X2(n) \times X2(n), \quad (15)$$

$$QX2(n) = \{LX2_p(n), LX2_p(n)X2_t(n), \\ LX2_t(n)/X2_p(n)\}. \quad (16)$$

A submultitude $LX2_p(n)$ define binary relations of the "ordering" type between subject manipulations of the 1st kind of one subset.

A submultitude $LX2_p(n)X2_t(n)$ define binary relations as type "composition" between subject manipulations of the 1st kind of different subsets.

A submultitude $LX2_t(n)/X2_p(n)$ define the binary relations as type "arrangement" between the subject manipulations of the 1st kind of the one subset.

Since subject manipulations are considered at the object level, any manipulation of the 1st kind is a variant of a certain type always. Since the type of manipulation is fixed on a certain multitude of structural units always, subject manipulation of the 1st kind, as an option, is fixed on a subset of this set of structural units:

$$x_{ps} = x_{ps}(p, t, u_{ps}). \quad (17)$$

The relations describing interrelations of the basic static and functional components of applied task model of object level can be represented in the following form:

$$R_2^{IP-1}(n) \subset C(n) \times C(n) \dots \times C(n) \times X2(n), \quad (18)$$

$$R_2^{IP-1}(n) \\ = \{r_1^{IP2-1} | r_1^{IP2-1}: (c_{n1}^r, \dots, c_{nl}^r) \rightarrow x_{ps}\}. \quad (19)$$

3 Analytical processing of the infological model

Analytical processing of infological models includes the following complex of tasks: determination and check of information connectivity between subject manipulations; analysis and restructuring of subject manipulations system; fragmentation of information. [2-4]

Checking information connectivity allows you to determine the possibility of restructuring the system of subject manipulations. To do this, it is necessary to obtain an information description for all subject manipulations (PM) - first elementary, then complicated, taking into account the type of algorithmic structure. As a result, a complete informational description of the algorithm as a whole should be obtained (complicated subject manipulation of the upper level), which is based on the informational description of all elementary (child) manipulations included in it.

Restructuring involves transforming graphical descriptions, which is difficult to do on diagrams without preparation. Therefore, first it is necessary to form a description of the process of performing subject manipulations in a different form. For this, a "conveyor - time step" approach was proposed and the apparatus of block matrices was chosen, which made it possible to present the manipulations system in the form of a structural description. The structural description takes into account the spatio-temporal characteristics of the algorithm execution process - the axis of the conveyors (K) is located vertically and the axis of the time steps (T) is located horizontally. [4, 5]

Let's present a structural description x_{pt} - complex subject dependence in the form of a block matrix H_{pt} :

$$H_{pt} = \begin{bmatrix} H_{pt}^1 & H_{pt}^2 \\ H_{pt}^4 & H_{pt}^3 \end{bmatrix}, \quad (20)$$

where H_{pt}^1 - matrix-column defines the external (input) information connection x_{pt} complex subject manipulation by input structural units of the "information attribute-5" type;

H_{pt}^2 - square matrix that defines the internal informational relationship according to structural units of the "information attribute-5" type between subject manipulations ($p + 1$) of the decomposition level. These subject manipulations are part of the complex subject manipulation x_{pt} ;

H_{pt}^3 – matrix-string defines an external (output) information connection x_{pt} complex subject manipulation by output structural units of the "information attribute-5" type;

H_{pt}^4 – matrix-element. It shows what type of algorithmic construction the description belongs to: 1-sequence, n-iteration, 0-alternative.

The dimension of the matrix H_{pt} is composed of sizes its constituent block matrices $H_{pt}^1, H_{pt}^2, H_{pt}^3, H_{pt}^4$ and dimension matrix is $m_{pt} = (m+1) \times (m+1)$.

For each basic algorithmic construction, a type of structural description is defined. For an algorithmic construction of the "iteration" type, the structural description is shown in figure 2, of the "alternative" type, the structural description is shown in figure 3.

$$H_{pt} = \left[\begin{array}{c|c} 1 & x_{(p+1)h} \\ \hline n & 1 \end{array} \right]$$

Fig. 2. Structural description of the algorithmic construction of the "iteration" type

$$H_{pt} = \left[\begin{array}{c|c|c|c|c|c} 1 & x_{(p+1)g} & 0 & \dots & 0 & 0 \\ \hline 1 & 0 & \dots & \dots & 0 & 0 \\ \hline 1 & 0 & 0 & x_{(p+1)r} & 0 & 0 \\ \hline \dots & \dots & \dots & \dots & \dots & \dots \\ \hline 1 & 0 & 0 & \dots & 0 & x_{(p+1)m} \\ \hline 0 & 1 & 1 & \dots & 1 & 1 \end{array} \right]$$

Fig. 3. Structural description of the algorithmic construction of the "alternative" type

To form a complete structural description for a task, structural descriptions are created for all complex subject manipulations. Further, the structural descriptions are included in the matrix describing the algorithm as a whole - a complex subject manipulation of the top level. When an element of a matrix (subject manipulation) is disclosed, its structural description specifies the elements that show the informational connectivity of subject manipulations at this level of decomposition. At each step of the iterative formation of a complete structural description, the dimension of the resulting matrix H_{pt}^* includes the dimensions of the base matrix H_{pt} and the embedded matrix $H_{(p+1)h}$. As a result, a matrix of the complete structural description of the task is obtained, where the horizontal shows the time spent on the task - time steps, and the vertical spatial chains - conveyors. [4, 6, 7]

Next, an extended structural description $\overline{H_{pt}^{2*}}$ is formed. This matrix is obtained by transposing the elements of the matrix H_{pt}^{2*} relative to the main diagonal.

$$\overline{H_{pt}^{2*}} = H_{pt}^{2*} \cup (H_{pt}^{2*})^T \quad (21)$$

Based on the extended structural description $\overline{H_{pt}^{2*}}$, you can transform the description of the system of

subject manipulation. To simplify the formal description, the block matrix $\overline{H_{pt}^*}$ is copied to the block matrix G_{pt} :

$$\overline{H_{pt}^*} \equiv G_{pt}. \quad (22)$$

$$G_{pt} = \begin{bmatrix} G_{pt}^1 & G_{pt}^2 \\ G_{pt}^4 & G_{pt}^3 \end{bmatrix}. \quad (23)$$

Studying the elements showing informational connectivity, one can draw conclusions about the possibility of restructuring the system of subject manipulations. Restructuring is the process of optimizing the algorithm for solving a task in terms of time and space expenses. Determination of the time characteristic (number of time steps) consists in finding the maximum time step number in the optimized structural description of the algorithm. Determination of the spatial characteristic (number of conveyors) consists in finding the maximum conveyor number in the optimized structural description of the algorithm. [8]

To obtain an optimal structural description by time steps, a formal description of the movement of the element of the main diagonal of the matrix-block G_{pt}^2 - the subject manipulation and all elements associated with it, one time step earlier, was performed. The movement of elements is performed only if there is no informational connectivity between subject manipulations. The absence or presence of informational connectivity between subject manipulations shows the value "0" or "1" in the lower triangular matrix under the main diagonal.

In the G_{pt}^3 block, the elements move according to the movement of the elements of the main diagonal. Blocks G_{pt}^1, G_{pt}^4 of the block matrix G_{pt} remain unchanged.

As a result of restructuring the system of subject manipulations of the first kind, an optimal structural description in terms of time characteristic is obtained in the form of a block matrix G_{pt} , which contains a horizontally compressed structural description of the matrix $\overline{H_{pt}^*}$. [8]

To simplify the description of restructuring process the system of subject manipulations of the first kind by spatial characteristic, the block matrix G_{pt} is copied into the block matrix Q_{pt} : $G_{pt} \equiv Q_{pt}$.

To form a structural description that is optimal along the conveyors, the lack of informational connectivity between the elements describing the subject manipulations is first determined. If the condition is met and two adjacent elements are independent, then the element of the main diagonal (the subject manipulation) is moved to another conveyor located above. Together with this element (the subject manipulation), all elements from this conveyor are moved. The move process is iterative.

Move rules: determine the last element on the main diagonal on the last conveyor (in the last row) of the Q_{pt} matrix; define the element that precedes it - subject manipulation. The presence (1) / absence (0) of informational connectivity is checked between them. If there is no information connectivity, then move. The

rules for moving elements of row are similar to the rules for moving when restructuring a structural description by time steps, only they move from the underlying row to the row located above.

When performing the restructuring process through conveyors, the main conveyor of the maximum length and additional conveyors to the main conveyor are formed. These conveyors, as a rule, contain subject manipulations of the "alternative" type as part of a given information-related manipulations chain. The blocks Q_{pt}^3 , Q_{pt}^4 of the block matrix Q_{pt} remain unchanged.

As a result of performing these actions, a block matrix Q_{pt} is obtained containing a vertically compressed structural description of the matrix G_{pt} .

Fragmentation of information shows the distribution of subject manipulations and their structural units of the "information attribute-5" type on performance time steps.

4 Conclusion

Restructuring is the main task of the analytical processing of system of the subject manipulation. The "conveyor - time step" approach, the rules for the formation and restructuring (optimization) of the structural description of subject manipulations were proposed, which allow the sequential process of the algorithm to be converted into a serial-parallel one based on the analysis of information connectivity between subject manipulations. The restructuring of the system of subject manipulations is very important because it significantly can reduce the algorithm execution time.

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