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THE METHOD OF DOMAIN MODEL CREATION USING FRAMES IN THE DEVELOPMENT OF MONITORING SYSTEMS

The paper describes an approach to the problem of creating a domain model, and a parametric model of controlled engineering objects. The approach is based on using set theory and the concepts of frames, explained all the necessary concepts and attributes of the models are explained, and an option is offered of a computer (machine) implementation.

Key words: *application domain, semantic object, frame, semiotic table.*

Introduction. Complex technical objects have long been widely used in various industries. To ensure continuity, reliability and efficiency of the associated process it is necessary to monitor the status of these objects. In our time monitoring and control systems (MCS) are developed and created for this purpose. The task of developing new and more sophisticated systems of this type is very pressing because of the need to ensure the monitoring of the ever-growing number of complex technical objects and the increased demands on the reliability and effectiveness of related processes.

In the development and creation of MCS the simulation of the controlled object must be as accurate as possible. In such systems it is also necessary to implement the system of expert decision-making support. All of these features require problem domain (PD) information to be stored in a database — the description of technical processes, characteristics of objects, the decision making rules. This information should be structured and organized for the most effective (cost of time and the output completeness for relevant queries) access to it. To do this, the task of constructing a correct semiotic model correctly of the selected PD is set. This article describes one of the possible way to solve it.

Properties and stages of PD development in MCS. For the formal construction of the semiotic MCS PD model and its specific linguistic content the most important stages are: the development of the actual MCS domain; its decomposition into components and classes of objects of different levels of complexity and organization down to elementary semantic objects; the study of the properties of objects, their structures of hierarchy, relationships and other system properties.

MCS domain is a complex system of our ideas about the definition of the categories of objects and phenomena of the real world. It reflects the merits of our knowledge of many areas of science and technology. MCS itself is one of the PD.

Subject area consists of a variety of objects and relations between them. In this context, any independent conceptual whole of real interest to us will be called a PD object, its component parts, if any, - the elements, and the object — a complex semantic object. Quantitative measure of the number of characteristics of the elements of a complex semantic object is called its properties. Between the elements of a complex semantic object, there is always some connection or relationship. A scheme of these connections shows the structure of the object and is called a network.

Most complex semantic object data domain MCS are dynamic. They have the ability to change the structure of their relations, and quantitative characteristics of the elements — the properties.

MCS mobility can only be achieved if there are formal tools developed declarative semantics of MCS PD and their relationships. In addition, there must be means to automatically generate intra-machine models of semantic objects based on declarative description.

The variety of connections and relationships between the semantic MCS PD allows the partitioning of the domain into a number of simpler subsystems of semantic objects. They themselves can be quite complex systems.

The set of semantic objects S of the domain R we will call the base set, and together with the notation $S(P)$ use the notation M_B. At the base set M_B can distinguish the set of subsets M_{B_i}, such that $M_B = \bigcup_i M_{B_i}$, i.e. sharing for some properties and characteristics semantic objects to a set of classes that can both intersect ($M_{B_i} \cap M_{B_j} \neq 0$) or not ($M_{B_i} \cap M_{B_j} = 0$).

The set of names of links or relationships between the semantic objects is called basic signature Ω_B connections and relationships of the domain on the base set M_B. Structure of the individual sub-systems of semantic domain Σ_i can be implemented in a subset of the relations in the signature Ω_B, i.e. in the signature Ω_{B_i}, where $\Omega_B = \bigcup_i \Omega_{B_i}$. The sets of semantic subsystems Σ_i of the MCS domain, regarded as a complex system Σ, enter into a fairly sophisticated communication and relationships. This produces other classes of semantic objects (subsystems) as Σ_i can be either disjoint classes of base semantic object set ($M_{B_i} \cap M_{B_j} \neq 0$) as well intersecting signature subsets ($\Omega_{B_i} \cap \Omega_{B_j} \neq 0$), in which they are defined.

MCS PD consists of a set of polymorphic semantic objects. Strict formal description of the structure of objects, their properties and relations between them and the development of a formalized model M_{Σ} of the MCS PD must be based on the methods of general systems theory.

A mathematical model of PD. In systems theory, as model (or a relational system) Ξ is considered a set of M with a given set of relations on it $\left\{r_1^{(i_1)}, r_2^{(i_2)}, \ldots, r_m^{(i_m)}\right\}$ with respective arity $i_1, i_2, \ldots, i_m$ and signature $\Omega = \left\{R_1^{(i_1)}, R_2^{(i_2)}, \ldots, R_m^{(i_m)}\right\}$ (relations names), where $r_j^{(i_j)} = \alpha\left(R_j^{(i_j)}\right)$. Ordered set (tuple) $\left(x_1, x_2, \ldots, x_k\right) \in \alpha\left(R^{(k)}\right)$, satisfying *k-ary* relation $r^{(k)} = \alpha\left(R^{(k)}\right)$, is a subset of the Cartesian product of $r^{(k)} = M \times M \times \ldots \times \times M$ *(k* times) of M.

It is important to understand that the mathematical model $\Xi = (M, \{r\})$ of an object or phenomenon of the real world is a model formulated in a formal theory $T = (\Omega, \{\Omega_B\}, \{\rho\})$. T is an axiomatic description of the most important selected properties of the considered object or phenomenon of obeying certain rules on the basis of a set of axioms $\{F\}$ of this theory and a set of inference rules $\{\rho\}$. Formulations of the laws of the proposed theory in the process of mathematical modeling of an object or phenomenon depend mainly on the level of knowledge about the nature of the object, on the level of knowledge about its relationship with the environment and on the level of abstraction in the modeling of both the object and the environment.

A convenient way to describe semantic polymorphic MCS PD is a logical construct called a systems theory framework: $K = ((M, \alpha), \Omega_2, E)$, or $K = (M, \{r_j\}, \{Q_j\}, \{E_k\})$, where M is the base set; α — a function which associates with the names of relations $\{R_j\} = \Omega_1$ in the signature Ω_1 a set of relations $\{r_i\}$, i.e., $r_i = \alpha\left(R_i\right)$, $\Omega_2 = \{\Omega_j\}$ — signature Ω_2 with a set of names of relations $\{\Omega_j\}$, which has no common relationship names with Ω_1, $E = \{E_k\}$ — a set of axioms, which involve the names of relations as of Ω_1, as well as of Ω_2.

Model $\Xi_1 = (M, \{r_i\})$ (or $\Xi_1 = ((M, \alpha))$ is called the base model skeleton in the signature Ω_1. At the same basic set of M the second model $\Xi_2 = (M, \{q_j\})$ (or $\Xi_2 = ((M, \gamma))$ of the signature $\Omega_2 = \{\Omega_j\}$ can also be determined with the function γ, which assigns to the names of relations $\{\Omega_j\}$ relations $\{q_j\}$, i.e., $\Omega_j = \gamma\{q_j\}$.

The state of the carcass is the model KS = (M, δ) in the signature $\Omega = \Omega_1 \cup \Omega_2$, for which function *б* and *∂* are the same in the signature, and thus the axiomatic E = $E_{\{k\}}$ is performed. Basic frame model is the articulation decomposition, and the frame itself — its representation. Names of relations — the essence of a possible relationship on the base set M, and the relations $\{r_j\}$ are already fixed in the base model.

Composition of frames $K_1 = \left(M_1, \left\{r_i^1\right\}, \left\{Q_j^1\right\}, \left\{E_k^1\right\}\right)$ and $K_2 =$ $= \left(M_2, \left\{r_i^2\right\}, \left\{Q_j^2\right\}, \left\{E_k^2\right\}\right)$ is the frame $K = \left(M, \left\{r_i\right\}, \left\{Q_j\right\}, \left\{E_k\right\}\right)$, for which $M = M_1 \cup M_2$, $\left\{r_i\right\} = \left\{r_i^1\right\} \cup \left\{r_i^2\right\}$, $\left\{Q_j\right\} = \left\{Q_j^1\right\} \cup \left\{Q_j^2\right\} \cup \left\{H\right\}$, $\left\{E_k\right\} = \left\{E_k^1\right\} \cup \left\{E_k^2\right\} \cup \left\{E_k^3\right\}$, where H is the name of a binary relation (interpreted as a correspondence between the base sets M_1 and M_2) $\left\{E_k^3\right\}$ — a set of axioms that define the type of composition.

System Σ (or its individual subsystems Σ_i) can be thus represented by a set of frames (polyframe). State of such polyframe Ξ = (M, $\{r\}$) is a concrete realization (model system), in which a basic set is the union of all basic sets of frames M_i ($M = \bigcup\limits_i M_i$), And a set of relations $\{r\}$ characterizes the relationship between all the elements of M, M_i and their possible compositions.

Principles of PD decomposition. MCS PD decomposition is a representation of it with frames. From the base set M_B object classes or subsystems are isolated. As a result we get a basic subset M_{B_i}. To construct the appropriate frameworks set of relations is fixed on them.

Semantic objects polymorphism is taken into account by construction of multiple frames on the same subsets of M_B and various frames compositions for the of non-intersecting or overlapping subsets.

The task of MCS PD decomposition is to build structural models of semantic objects $S(P)$ in order to find the best mapping λ: S(P) $\to L(G)$ of the set $S(P)$ in a problem with the grammar G of the language L. Therefore it is necessary to strive to:

- carry out a reasonable compromise between the complexity of a formal description of the machine models of general systems theory and the necessary level of detail and abstraction from non-existent properties (minimizing the total number of modules and their composition);
- when considering the subject-matter with certain positions for the synthesis of various semantic models of complex objects maximize use of an already established classification;

- achieve such a partition into subsets and the types of relationships that would form the tree-like or fairly simple networks, which can be graphically presented using graphs;
- identify a hierarchy of semantic subdomain for hierarchical structuring of the MCS problem language;
- achieve models homogeneity inside of a semantic structuring systems in order to structure MCS problem languages into problematic sections.

Using semantic networks and frames in the PD decomposition. Successful solution of these problems is possible only if there is a certain formalism of knowledge representation in a computer. Ongoing work in this area has shown that the most effective way of formal knowledge representation are semantic networks.

The reason for the wide application of semantic networks is the versatility of the conceptual basis used in them. Specialization in the semantic network is represented by a directed graph with labeled nodes and arcs, and vertices correspond to certain semantic objects, and arcs — to the semantic relationships between these objects.

In databases the smallest unit of information is a basic object. The set of elementary objects in the database is divided into subsets — categories that have a unique name — aspect. Any object is represented by an elementary scalar value of a certain type.

The tops of the semantic network in the presentation of its elementary objects can be attributed: each vertex is mapped to an attribute. Semantic network of this type of relational form corresponds to the data description in the syntagmatic chain language. Elementary syntagm — an element of a syntagmatic chain — has the form $\tau_1 R \tau_2$, where τ_1 and τ_2 are elements, and R — a relation, fixed between them.

In more complex semantic networks of complex objects may be put into databases — data structures. Their base set, in order of increasing precedence, comprises: data element, data group, the group relation database. In the domain group is a linear combination of components (attributes). In the field of artificial intelligence greater use is made of the semantic network of frames, frame-based languages generalizing relational type languages. There is a shift from single-level descriptions of relational type to multi-level, hierarchical descriptions with frames of different levels.

The term «frame» was proposed by the American cybernetics M. Minskii [1]. From the point of view of the formal theory the frame is a formal pattern that matches a certain event, phenomenon, state. It is a collection of information that characterizes the event or condition. This informational data corresponds to specific areas of memory reserved for the data types of information called «slots». To get a frame from a complex medium of concrete knowledge about reality (an instance of the frame), the slots have to saturate specific data. The greater the number of slots in the frame, the more diverse, and more versatile system will be able to be described by it.

Semantic frame-based networks consist of abstract and concrete networks. Abstract network meanwhile are complex frames, and specific ones are instances of these frames. In the domain all the concepts are arranged hierarchically, forming, when generalized, a superconcept (more complex semantic objects), and when detailed — subconcepts.

Computer models of MCS PD. In MCS information is of semiotic nature. This allows a unified approach to the creation of computer models of MCS PD based on semantic networks and the problem of recognition, retrieval and presentation coming from the designer's sense of information — the input assignments for MCS. This information has meaning only in relation to specific project activities. Its understanding is the structuring of information in accordance with its intended use — the process of filtering the information based of which the frames are activated and filled with the information from the original job.

Despite the variety of MCS PD semantic objects, they can be represented as simple semantic objects, i.e. the MCS PD data decomposition and structuring can be performed. Polymorphism of the MCS semantic objects is also a subject to decomposition on the individual MCS PD subdomains, the stages of design, design objectives, types of technologies, methods, solutions, etc.

As a result, you can identify the most common types of semantic objects used in solving specific design problems in which the frames are fairly simple structure, and the slots are of a permanent fixed type of information (data). Such a frame is a way of representing the semantic object that has strictly fixed dimensions (attributes) and can be represented as a tuple of attributes with the strict order of the sections of memory to be allocated under the slots (attribute values). Subconceps hierarchy defining this semantic object is fixed using the group relation 1 : т.

Semantic attributes of a relational table. Let’s consider such infological object as a semantic relational table with a group ratio of 1 : т. Its elements are the attributes values (complex or simple). Group ratio 1 : m is the ratio of the strictly (tree-like) order.

The formal description — a pattern in which the table is filled with semantic information (attribute values), — will be a simple frame. To implement the semantic objects of MCS PD and fix types of intra-machine representations the following model of attributes, frames and subframes is proposed in [2].

Semantic table attribute is a local attribute. Its scope is a semantic table, i.e. superconcept (semantic object), of which it is a simple concept.

The composition of any attribute or a more complex object includes the name of the concept of I_1. It is a symbolic value that represents the PD concept mnemonic name, that can include the words of a natural language (handles) Mnemonic names are interpreted as references to the concepts in the domain dictionary (thesaurus) with which pragmatic relationships between natural language words (PD concepts) are set.

Semantic attributes of the tables are divided into simple and complex. Simple semantic attribute table A_1 is defined as follows:

$$A_1 = (I_1, I_2, VT, MC, MA, KI),$$

where I_1 is the name of the concept; I_2 is an attribute intra-machine representation identifier; VT — the type of the attribute value (character string, integer, real or logical constant): MC — memory capacity in bytes (minimum and maximum), reserved for the value of the attribute; MA — address in memory (semantic table), KI — a key identifier (token).

The second type of attributes A_2 is an array of simple attributes of type A_1 and is represented as

$$A_2 = (I_1, I_2, N, ME, VT, MC, SMA, KI),$$

where I_1, I_2, VT, MC, KI have the same meaning as for the simple attribute A_1; N is the actual number of elements, ME — maximum number of elements in the array; SMA — first element value recording start address.

The ID attribute of the array A_2 is I_2 = <key, name>. It consists of the *MAS* keyword and an identifier.

A third type of attribute is a group of three different types of attributes that together make a subconcept of higher hierarchy, made of simple concepts, but not being a superconcept (it comes as part of a superconcept).

The group is represented by six objects

$$A_3 = (I_1, I_2, N, SMA, KI, \{A_{ij}\}),$$

where I_1, I_2, SMA, KI have the same meaning as for the attributes A_1 and A_2; N is the number of attributes in the group; $\{A_{ij}\}$ — *a* list of simple attributes of one or arrays of simple attributes A_2 $(A_2 = 1, 2)$.

Identifier I_2 *starts* with a keyword *GR,* followed by a unique group name.

A fourth type of attribute A_4 completes the hierarchy of semantic attributes of tables and an array of attribute groups:

$$A_4 = (I_1, I_2, N, ME, MA, K1, A_3),$$

where A_3 is the name of the group; N — the actual value of the array of groups, ME — the maximum possible number of elements in the array of groups.

The ID I_2 for attributes of type A_4 starts with the keyword *MGR.*

These four types of attributes in sufficient detail reflect the necessary means of providing tree-type superconcept of the PD with up to three levels deep.

High nesting level can be achieved either by using the concept of decomposition of the attribute of the fifth type — subtree represented by a five, which may also contain subtrees themselves

$$A_5 = (I_1, I_2, MA, K1, A_3, \{A_{ij}\}),$$

where $i = 1, 2, 3, 4, 5$; $\{A_{ij}\}$ — attribute list of types 1—5.

The ID I_2 for attributes of type A_5 starts with the keyword *TR* (tree).

Elementary frame (system-structural view) of a superconcept describes through concepts included in it a pattern of semantic tables and appears as a triplet

$$F = (I_1, I_2, \{A_{ij}\}),$$

where I_1 — superconcept name; I_2 — semantic table pattern identifier, starting with the keyword *PATT;* $\{A_{ij}\}$ — the list of attributes of the semantic table patterns.

Subframe (superconcept of higher hierarchy) is a formal description of a complex semantic object based on the composition of frames and is represented by:

$$SF = (I_1, I_2, \{F_{ij}\}),$$

where I_1 — superconcept name (complex semantic object); I_2 — subframe pattern identifier, starting with the keyword I_1, I_2, SUBF; $\{F_{ij}\}$ — list of elementary frames or subframes, that are part of the subframe.

Thus, the subframe is a complex object in a semantic tables hierarchical set (tuple).

Subframe may be formed as a composite of two frames or the other set-theoretic operation on the attributes of frames.

In this case, it is given by a syntagm (three objects), which includes the names of the two frames (semantic tables templates) and the name of the semantic function with a certain set of parameters indicated.

Subframe (frame) of this type will be described as following:

$$SF = (I_1, I, F_{1j}, F_{2j}, SM_k, \{P\}),$$

where I_1 and I_2 are respectively superconcept name and subframe template ID; F_{1j} — the first frame of the *j-type,* F_{2j} — second frame of the *j-type;* SM_k — the name of a semantic function, $\{P\}$ — the list of parameters.

For a list of options attributes of the first and second frames can be taken, which will join the subframe in accordance with the function of SM_k.

List of parameters $\{P\}$ can be for a number of functions blank if subframe is formed by a simple composition of frames

$$FM = FM_1 \cup FM_2,$$

where FM_1 — set of named attributes of the first frame and FM_2 — a set of named attributes of the second frame, FM — a set of non-recurring subframe named attributes.

Composition of frames and subframes can form quite complex tree-like semantic network. Implementation of semantic chains with more complex kind of group relation: *n*: *m,* i.e .representation in the form of frameworks and systems, can be achieved by introducing a number of special semantic functions, allowing to get new frames and subframes based on the theoretic set transformations on the sets of semantic tables attributes.

These transformations can be specified by the syntagmatic chain language (procedural knowledge) in the form of syntagm chains $\tau_1 r \tau_{2,}$ where τ_1 and τ_2 are semantic objects; r is a mapping operation, the semantic function.

Intra-machine representation of the MCS PD will be a semantic network, i.e. a compound semantic object. Since the MCS PD model is a collection of intra-machine representations in the form of frames of declarative knowledge we will identify it with the knowledge base and denote as β.

The base of β is a semantic frame network of semantic tables patterns, i.e. ordered set of composite semantic objects S_β. It appears in the form of attribute-based, labeled graph $GR_\beta = (W, R)$ with the set of attribute nodes labeled W and the set of marked edges labeled R with the marking functions ψ_1 and ψ_2, i.e.

$$\psi_1 : W \to \Omega_W \text{ and } \psi_2 : R \to \Omega_{R,},$$

where $\Omega_W \cup \Omega_R$ is an operation signature on composite objects of the base S_β, where:

$$S_\beta = \{W, L, \psi, B_0, A, D\},$$

where $L \subseteq M \times M \times N \in LR$ — set of ordered links; ψ Ч a set of the functions of marks, B_0 — set of initial vertices (for superconcepts or concepts) A — the set of attributes; D — set of attributes implementation scopes.

To implement the m-ary operations $m \geq 0$ of signatures $\Omega = \Omega_W \cup \Omega_R - \bigcup\limits_{m \geq 0} \Omega_m$ we will use a variety of semantic functions that perform set-theoretic, logic, arithmetic, symbolic processing, and the like; operations on semantic objects S_β of the base *в*, subframes, frames, their attributes and names for the formation of new superconcept in terms of frames and semantic tables attributes, fixing semantic objects polymorphism. Based on the representations of subframes SF, frames F, semantic attributes of tables A_1 — A_5 a declarative representation of the domain model is built as a base *в* in the language of the base declaration.

It is proposed [2] to include base declaration language in the metalanguage of the first group, serving as means of describing MCS input languages.

The inclusion of base declaration language in this meta-language allows the simultaneous declaration of base and description of the syntax and semantics of the MCS input language. It is possible to automatically select a group of semantic objects that are directly in the MCS input tasks, not the result of any of the project activities.

This allows the attribute markup of grammatical concepts through the attributes of the source language semantic tables and subframes.

The inclusion of base declaration language into the meta-languages that describe the MCS input language allows for the following features:

- declarative mapping of MCS PD P semantic objects into a set of composite semantic objects $S_в$ of the base $в$ (machine domain model) θ: $S(P) \rightarrow S_\beta \in \beta$, and inverse mapping θ^1: $S_\beta \rightarrow S(P)$;
- simple description of the attributes that make up the semantic description of the table with their simultaneous intra-machine representation;
- simple relationship between the MCS input language grammatical concepts, PD semantic objects $S(P)$, the composite semantic objects $S_в$ of the base $в$ in the form of attributed semantic tables and subframes, i.e. implementation of maps of the form $L \rightarrow S(P) \rightarrow S_\beta$ by using an attribute markup language grammar with modified Backus — Naur forms;
- the use of attributed grammars to describe the syntax and semantics of the input language with linking input language semantic objects to I PD P semantic objects $S(P)$ and with the composite semantic objects $S_в$ of the PD computer model — base $в$.

Conclusions. The proposed method allows to build a PD model for use in MCS and expert decision-making support systems, and also to build parametric model to manage complex technical object using information on PD.

Selected mathematical apparatus makes the method versatile and suitable for use in a variety of areas — management of energy facilities, expert decision-making support systems, etc. For the high level of formality it is possible to build not only mathematical, but also a computer model.

References

1. Attardi G. Логика описания для построения баз знаний / G. Attardi, M. Simi. — ТИИЭР, 1987. — Vol. 75, № 2. — P. 47–58.
2. Araksian V. V. К проблеме формирования универсального диалогового интерфейса в интеллектуальных системах / V. V. Araksian, N. A. Gerasimov, A. M. Likatskii // Proceedings of the All-Soviet Union seminar «Логика и организация диалоговых процессов в интеллектуальных системах». — Novosibirsk, 1988. — P. 51.

У статті описується підхід до проблеми створення моделі предметної області, і параметрична модель контрольованих інженерних об'єктів. Підхід заснований на використанні теорії множин та концепції кадрів, пояснив всі необхідні поняття й атрибути моделі, варіант пропонується в комп'ютерній реалізації.

Ключові слова: *домен програми, семантичний об'єкт, рамка, семіотичної таблиці.*

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