SYSTEMOLOGICAL KNOWLEDGE-BASED TECHNOLOGY FOR SOLVING COMPLETE ILL-STRUCTURED PROBLEMS

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Abstract: Original method and technology of systemological «Unit-Function-Object» analysis for solving complete ill-structured problems is proposed. The given visual grapho-analytical UFO technology for the fist time combines capabilities and advantages of the system and object approaches and can be used for business reengineering and for information systems design. UFO- technology procedures are formalized by pattern-theory methods and developed by embedding systemological conceptual classification models into the system-object analysis and software tools. Technology is based on natural classification and helps to investigate deep semantic regularities of subject domain and to take proper account of system-classes essential properties the most objectively. Systemological knowledge models are based on method which for the first time synthesizes system and classification analysis. It allows creating CASE-toolkit of a new generation for organizational modelling for companies' sustainable development and competitive advantages providing.

Keywords: systemology, conceptual classification model of knowledge, natural classification.

ACM Classification Keywords: I.2 Artificial Intelligence – I.2.6 Learning: Knowledge Acquisition

Introduction

For optimal decision making, sustainable development of humanity, companies and organizations; for competitive advantage providing new powerful methods and technologies for solving modern complex ill-structured problems in different spheres are necessary. We work with complete ill-structured (symbolic, etc.) qualitative problems in low-formalised problem domains, including systems of the first nature (e.g. social). For solution such problems and analyse such systems we need more powerful system approach and knowledge-based methods and tools. So we use new systemological methodology, which for the first represents features of system methodology of noospheric stage of science development.

This methodology makes it possible to reveal the essential properties of complex objects of an arbitrary nature, and also the reasons for their occurrence, adaptation, and development, and, consequently, to predict and manage any complex system more efficiently. The quality efficiency of this methodology determines the necessary of its use in application fields of an arbitrary nature, including for construction of a picture of the world as a whole [Bondarenko et al, 1996].

Systemology as modern promising system methodology does not regard system as a set but as a functional object which function is assigned by hypersytem. Systemology in particular allows overcoming problems of traditional methods of system analysis at the expense of using conceptual knowledge as well as formalizing procedures of analysis and synthesis of complex systems and creating knowledge-oriented software tools for their simulation [Matorin, 2001a], [Matorin, 2001b], [Matorin, 2001c].

Nowadays there is a variety of information systems and technologies for supporting decision takers in various ways. These technologies and systems include in particular technologies for system analysis and information systems that it automates and represent software CASE-instruments for business systems and business processes simulation. We can give here only few aspects of new technology based on functional systemology.

Let us consider some results of creating original method of systemological «Unit-Function-Object» analysis based on systemology and conceptual models of knowledge [Matorin et al, 2005], [Matorin and Elchaninov, 2002].

Technology of Systemological UFO Analysis

Complexity of business, managerial and production problems is growing constantly. This leads to the fact that at the present stage competitive activity of organizations and making optimal decisions become impossible without designing and reorganizing business processes (business reengineering). To solve the problems of reengineering visual graph-analytical methods of analysis and systems simulation are used. They are the varieties of methods of the system-structural analysis (e.g. SADT, DFD) as well as object-oriented analysis (OOA) using UML. Employment of these methods has been automated with the help of CASE-means (e.g. BPwin, Rational Rose).

At present according to most analytical practitioners and consultants the efficiency of existing traditional CASE-means does not comply with modern requirements, e.g.:

– Using the toolkit for automation of system-structural analysis poorly supports development of object-oriented software applications (most popular and in great demand nowadays), that complicates the choice;
– Using the existing simulation toolkit leads to extra diversity in presenting organizational models;
– Using the toolkit that automates object-oriented analysis methods does not allow adequate representation of business processes in organizations.

CASE-means possibilities are always limited by built-in systems simulation methods. For that matter and for the above mentioned problems activities aimed at creation of theoretical, methodological and instrumental tools for complex systems simulation free from the above drawbacks have been carried out. Investigations in this area have made it possible to develop new ingenious method and algorithm for analysis and simulation of the systems that allow representing the system as a triennium structure "Unit -Function-Object":

– "Unit" is the cross point of input and output connections (flows of any nature) in the structure of simulated system;
– "Function" is the process of conversion of input into output, i.e. the process ensuring balance of "influent" and "effluent" flows of the given node;
– "Object" is the substance, which implements the given function.

The given method (UFO-analysis), which for the fist time combines capabilities and advantages of the system and object approach, is designed for project implementation in business reengineering and may be oriented for simulation and designing information and engineering systems with a help of unique CASE-toolkit ("UFO-toolkit").

Developments in the systemological approach [Bondarenko et al, 1996] to poorly formalized subject areas have led to a new systems theory that overcomes the set-theoretic approach to systems and instead describes specific system properties and relations [Matorin, 2001a]. The concepts from that theory give a formal semantic system with an adaptive alphabet, which serves as the basis of a new systems analysis method (UFO-analysis), which agrees with the requirements and procedures of object-oriented analysis and design (OOAD) in information systems [Matorin, 2001b], [Matorin, 2001c].

This agreement has been obtained by solving the following auxiliary problems:

– setting up a method of identifying a class set as required and suitable for OOAD;
– introducing conceptual classification simulation (CCS) procedures into systems technology.

Both of these amount to setting up a universal conceptual classification model for any subject area. That model constitutes a classification of all the components and properties of a system. The abstract level is considered as a basic one and specifies the category structure, which determines the method of selecting the classes needed for the simulation. The particular (sheet) classes in this classification scheme (and also examples of them) are used to simulate a particular subject area. They also provide the alphabet for the normative system in the new systemological analysis method.

The basic classification is a high-level conceptual classification model (taxonomic and parametric) for forms of system considered as flow objects and also for forms of their functions and structures (fig. 1).

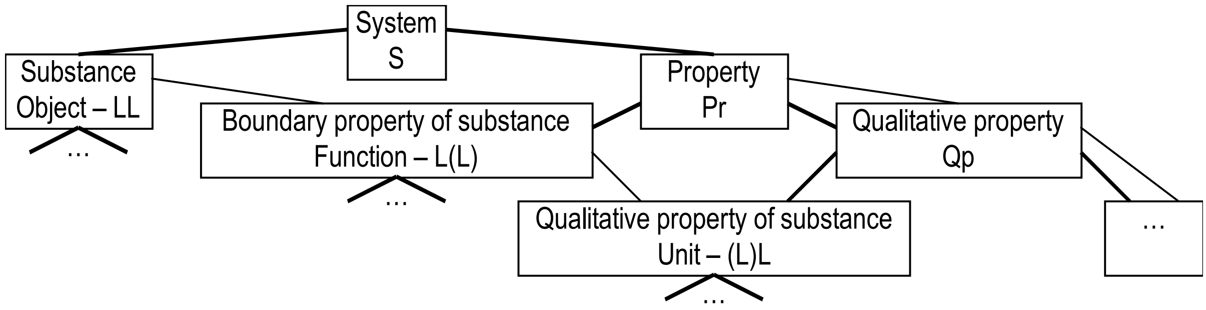

Fig. 1. Basic classification

This classification is a modification of the [Matorin, 2001a] scheme, and the “system” concept is at a limiting level of abstraction, and thus as in [Matorin, 2001a] represents a unique category (root class).

It is best to distinguish primarily objects having boundary properties in the complete system set, of which the most important are the functional properties or “functions”. At the same time, it is best to distinguish properties characterizing qualities (“qualitative properties”).

In systemology, the properties of a system are understood as signs of its activity and are included in these connections and exchange flows with other systems in the supersystem structure. This means that one analyzes system properties by means of functional systemology in terms of an integral object "based primarily on the observation of those fluxes in which it is included as an element of a superobject, i.e., as a flow element in a network of closed exchange flows in the superobject. Naturally, these qualities will be observed simultaneously and a sufficiently complete characteristic of the function of this object is thereby provided, which gives an expression of the integrity, since in qualitative characteristics one cannot get a balance between the incoming and outgoing flows in that case" [Melnikov, 1988].

It is thus best to consider as qualitative properties of a substance or object its capacity to be a unit in a certain structure. The capacity to function at that unit supports the balance between influx and efflux on the incoming and outgoing links, i.e., the capacity to transform the elements of the incoming links into elements of the outgoing ones, which will constitute boundary properties of the object or system (formal ones, in the present case functional ones).

The objects in this hierarchy are thus classified in accordance with the functions they perform. From the formal logic viewpoint and on the basis of the structural properties of that classification, one can write a genus-species definition: “An object is a system characterized by a function”. This completely corresponds with the systemological concept of a system as an object with functions on the basis that a system is always also a flow object. Then also in accordance with the systemological approach, a function of an object is considered as one of its internal determinants, i.e., the cause of certain internal substance characteristics of it.

The functions in this hierarchy are classified in accordance with the flow units that they constitute in the system structure. Consequently, from the viewpoint of formal logic and on the structural properties of that classification, one can write a genus-species definition: “A function is a property or capacity to be a unit in a system structure”. This means that a function is characterized by the elements in the incoming and outgoing links on which flows are exchanged with other objects. The region of definition for that function is the set of elements forming the input flows (links), and also the region of values, namely the set of elements forming the outgoing flows (links).

In accordance with the systemological approach, the flow (link) characteristics of a unit in the supersystem structure are considered as an external determinant for the system, i.e., the cause of a certain internal determinant or current function.

This scheme resembles the [Matorin, 2001a] one in constituting a taxonomic parametric classification, in which the objects are classified in accordance with their properties, forming part of the general class hierarchy. This means that in this hierarchy, as in [Matorin, 2001a], for each object (class or concept) there is not only a generic feature (higher-level class) but also a concept (class) having a species difference in content for the concept, i.e., the property of the object. The dashed lines in fig. 1 show the relationship of a concept with its species difference (class and properties). As this classification is parametric, it enables one to classify system species in accordance with their property species, i.e., to incorporate the natural classification laws [Solovyova, 1999] as metaknowledge. Conceptual classification models of knowledge are based on systemological method (systemological classification analysis) [Solovyova, 1999], which for the first time synthesizes system and classification analysis on the basis of the new criteria of natural classification. They help to investigate deep semantic regularities of subject domain and to take proper account of system-classes essential properties the most objectively. It allows receiving the forecasting parametrical classifications and effective ontologies in different ill-structured problem domains also.

If one considers a system as a flow object whose function is due to a function in a superobject (supersystem), one can represent any particular system S* in terms of a class hierarchy, as in [Matorin, 2001a], with that system being an example of class S, and put formally as the triple S* = <LL, L(L), (L)L>, in which (L)L is a particular unit in the supersystem structure ((L) is an incoming link, L an outgoing link), with L(L) the class of functions that balance the given unit ((L) is the argument and L the function), and LL is the class of objects that realize the given functions (L object input, L object output). We call this triple a UFO-element.

Here L denotes the type of elements with a material or information nature (L = {M, I}, with M a material element and I an information one; M = {V, E}, where V is a substance element and E an energy one; and I = {D, C}, where D is of data nature and C is of control nature), which applies at a certain level in the connected systems, and which these systems use to exchange data through their links, which are considered as flows (fig. 2).

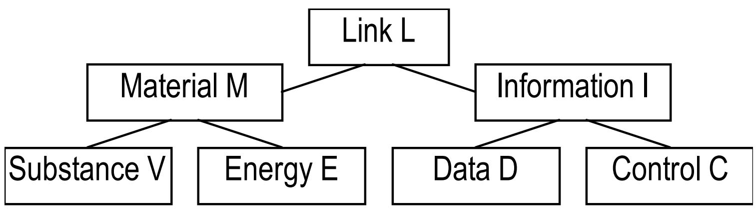

Fig. 2. Initial link classification

This representation of a system as a phenomenon corresponding to an example of a UFO element agrees well with the concept of “generator” (“generatrix”) in pattern theory [Matorin and Elchaninov, 2002]. By “generator” in that theory [Grenander, 1979] one understands an object having certain features α, as well as the incoming and outgoing links (in turn characterized by certain parameters β). In our case (fig. 3), one can consider the examples of classes LL and L(L) as features of the generator, while (L) and L are links whose parameters are of type L (fig. 2). Then the generator g_i as an example of UFO element takes the form $g_i = \langle L_2^i\, L_1^i,\ L_2^i\,(L_1^i),\ (L_1^i)L_2^i \rangle$.

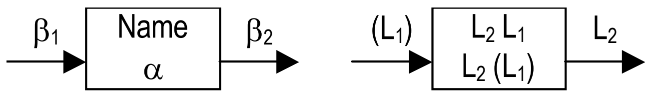

Fig. 3. Graphical formalisms – generator and UFO-element

Pattern theory involves the assumption that is a source that generates the set of generators $G = \{g_i\}$. In our case, that source generates UFO elements (generators) and is shown in fig. 1 as part of the basic classification.

The hierarchy there constitutes the basis of a normative system in the new method of systemological analysis. The alphabetic symbols are UFO elements representing particular classes (sheets) in the classification scheme, and also the corresponding examples of those classes. The examples of UFO elements are used here to construct system-object models for systems and also to simulate the functioning of these models.

This alphabet consists of characters for the units, functions, and objects representing a system from the viewpoint of its structural, functional, and substance characteristics respectively. Isomorphism in classifying those three (in accordance with the laws of natural classification) enables one to consider a single combined hierarchy containing UFO elements. A UFO element is a system that corresponds to a certain unit (intersection of links or flows) in the supersystem structure, with a defined function (in general not unique) that balances the flows at that unit and a defined object (in general, not unique for each function) that realizes the given function.

Incorporating the natural classification laws and criteria into the basic classification gives an unambiguous formal-logic definition for each object in terms of the genus and the species difference.

Fundamental constructive criteria and a method of natural classification formulated on the basis of the study and modelling of the regularities of the structure of conceptual system, which reflect the systematic character of reality (a subject field) you can find in details in [Solovyova, 1999]. For example one of them is: ”Essential supporting properties of any system are essential properties of its subsystem and species of its essential functional property. The concepts of essential supporting properties of a system are the concepts of essential functional properties of its subsystems – the species of the concept of the essential functional property of the system”.

On the basis of these criteria, it is possible for any subject field: to construct a classification reflecting essential properties of objects and different aspects of considering them; to estimate any classification in terms of the degree of inclusion of essential properties; to define errors and inaccuracies of any classification and specify their sources and possible remedies; to predict the evolution of any classification; to correct the terminology of subject fields.

A conceptual system is limited to the category and individual concepts. A hierarchy of systems is limited to the supersystem and specific systems. Theses facts should be taken into account in the application of the criteria. A through analysis of a natural classification has established the validity of the criteria for concrete systems as well (individual concepts) if subsystems are defined at functional components of the systems. This fact confirms the important assertion that the classification by “part-whole” principle for concrete systems (functional parts) and the generic-specific classification for external systems (functional genera and species) are essentially analogous and can be viewed in the framework of an integrated natural classification of class systems according to their essential functional properties.

Classification scheme thus acts as an algorithm for the semantics of the normative-system signs, which transforms that system into an algorithmically constructed one. Consequently, this scheme provides an alphabet for that system having not only a completely abstract or strictly mathematical semantics but also an object-oriented form, so that alphabet can be considered as a formal-semantic one, while the normative system is also formally semantic. This implements the current suggestions of informatics experts, who consider that there has long been a practical need to transfer from formal mathematical analysis of information phenomena to content analysis and the driving force in self-organizing systems of social nature.

Using a classification to generate alphabetic characters that constitute examples of the corresponding classes provides, as in [Matorin, 2001a] a distinctive feature for the alphabet. An ordinary formal system with a finite or infinite formal alphabet uses a finite and restricted number of initial concepts corresponding to the signs in the alphabet. This means that completely different subject areas are simulated by means of the same set of alphabetic characters in the normative system of some traditional system analysis method. On the other hand, specifying an alphabet by means of a classification can change the composition of the initial concepts and the corresponding alphabetic characters, i.e., allows one to adapt the alphabet and the normative system in accordance with the subject area.

This hierarchy (units, functions, and objects) enables one to use a detailed set of simulation facilities, i.e., alphabetic characters, to handle a particular task. For example, to simulate information business (such as organizations in the media), one can distinguish particular classes related to the data links and classes related to substances and energy, as well as ones in the form of abstract classes; to simulate electrical power businesses, it is necessary to specify the classes joined by energy links; and to simulate the transportation companies, one uses classes with substance links; and also to simulate production, one uses classes that simulate obtaining substances of appropriate form. The only thing overlooked here is a principle in accordance with which the properties of objects (functions and units) used to set up an object model are determined by their parametric taxonomic classification, i.e., by the basic class hierarchy incorporating those properties.

Specialization in the UFO element class hierarchy gives models defining the alphabetic elements for systems that incorporate more detailed forms of link on account of the consideration of the forms of material link: substance V and energy E, and also forms of information link: data D and control C. As a result of such specialization at this level, one can obtain for example the following classes of UFO elements (fig. 4), which are defined by the corresponding units and are considered as nonintersecting classes of generators constituting set G.

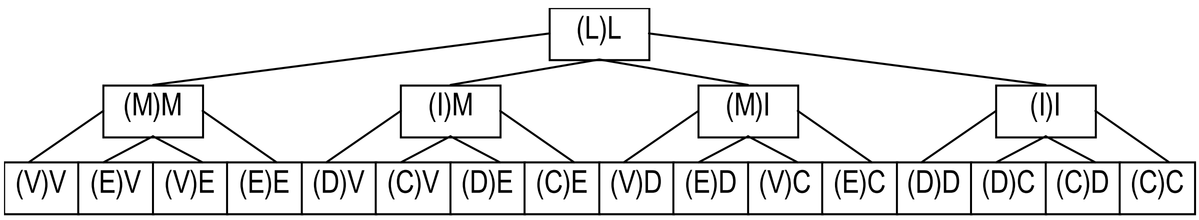

Fig. 4. Classification of alphabetic UFO elements by their units

The UFO analysis algorithm has the following basic steps [Matorin, 2001c]:

– identifying units and links from the functional links of the system as a whole;

– identifying functions performed by the observed units;

– identifying the objects corresponding to this functionality.

The UFO hierarchy adaptation for the initial steps in the algorithm consists in specializing it as regards particular units, functions, and objects in the subject area, i.e., it produces an ontology model. The UFO element specifications in that case will contain the following information:

– For the object (substance parameters): engineering and working characteristics (design, climatic and mechanical working conditions, reliability, necessary and available stocks of energy, materials, and information, as well as productivity and so on); attributes and quantitative characteristics of input-output ports (including flow capacity) and also the cost and working time. Here it may be useful to rank objects on various features.

– For a function (process parameters): description of the input to output conversion, i.e., the functional protocol; formal description of the functional dependence if it exists and is necessary in the form of a script or macro. In essence, this represents data on the internal determinant of the corresponding system.
– For a unit (structure parameters): type of link. In essence, this represents data about different cases in the use of the object, i.e., on the external determinant of the corresponding system.

If the alphabetic elements are software objects realized in the form of ready-made classes, one can say that UFO analysis is a component of the appropriate technologies under CORBA (Business Object Facility – BOF). In the latter case, the CASE software facility that automates the UFO analysis may function within the framework of the business object component architecture (BOCA) as a framework, which works as a tool for linking business objects into a system and provides a form of convenient working points for carrying out the tasks imposed on it.

To compare the proposed method and developed toolkit against most popular methods and toolkits special comparative simulation has been carried out using SADT/IDEF0 (BPwin), UML (Rational Rose) and UFO-analysis (UFO-toolkit) of the real business process "passing of the contract at the enterprise", as described e.g. at www.devbusiness.ru. Comparative research of methods and toolkits for business-systems simulation have been carried out on known criteria of leading analysts (e.g. G. Kalyanov), and such tool-kit should provide: recording of information on business processes; producing high-level representations of business processes; maintenance of repository; control of business processes description syntax; control of its completeness and model consistency; analysis and verification of processes description and generation of corresponding reports; producing specifications of business processes. Comparison of methods and toolkits for business modelling is presented in the table.

№	Comparison criterion	IDEF0/ BPwin	UML/ Rational Rose	UFO-analysis/ prototype
1	Possibility to orient methodology and toolkit at subject area	-	-	+
2	Possibility to reduce diversity of models representation	-	-	+
3	Possibility of syntactic and semantic control of business system and business process description	+/-	-	+
4	Availability and maintenance of depositary (library)	-	-	+
5	Possibility of component simulation technology support	-	-	+
6	Possibility of software object-oriented design support	-	+	+
7	Number of models types (diagrams) to be designed	3	4-5	1
8	Possibility of models construction automation	-	-	+
9	Simplicity/complexity of using methodology	+	+/-	+/-

If on the other hand technical objects are considered as alphabetic elements, then the UFO analysis will be matched to the CALS technology.

Conclusion

The basic class hierarchy has been used in proposing an alphabet that can be used to construct system-object models for example for organizations. That alphabet together with the system decomposition rules can constitute a formal semantic normative system, whose features are as follows:

– It objectivizes object and class decomposition for the system;
– It provides a range of functional objects (alphabetic symbols) for each form of system in accordance with a unified principle;
– It provides for simulating by computer the properties of the classes and the examples of object models.

That normative system allows one to formulate the UFO analysis algorithm for a system analysis method in which the procedures and results for the first time agree with the OOAD requirements.

Method of systemological classification analysis on the basis of natural classification has advantages in comparison with other method and has been used for conceptual and ontology's modeling and in artificial intelligence systems. Given UFO-method and tool as stated above have a number of advantages in comparison with existing business simulation methods and CASE-means.

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