# THE SYNTHESIS TECHNOLOGY OF COMPLEX SYSTEMS' IMITATING MODELS BASED ON CONCEPTUAL PATTERNS

**Kodema Vyatcheslav Alexandrovich**

Institute for Informatics and Mathematical Modelling at the Kola Science Centre RAS
Murmansk Region, Apatity

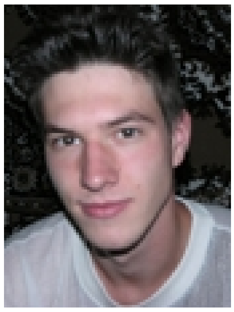
*KodemaSlava@rambler.ru (Vyatcheslav Alexandrovich)*

**Abstract**

At present modelling is the basic method for learning and predicting behavior of complex systems. At last years the complication of systems is followed by the integration process. In other words, the systems of different fields are joined in the whole. A large integrated system is appeared as a result, which has large functional abilities and complex hierarchical structure with big set of elements and subsystems. For developing models of such systems the efforts and knowledge of one specialist is not enough. So it is necessary a group of experts of different fields of sciences to do it. As a consequence of it, the complex macrosystem's model's development process is reduced to decomposition of the model-based object on subsystems and for each of them an expert or experts' group are selected which are responsible for developing model of separated subsystem. After the completing of each submodel development the process of synthesis is started. This work is aimed at developing a technology of synthesis of complex systems' imitating models through the technology of conceptual patterns and developing the tools of automation synthesis' process of such models which must support the work of experts' group. As a result, the developed tools significantly increase the developing models' correctness and decrease the period of their constructing.

**Keywords: Conceptual patterns, Imitating models, Complex systems, Synthesis, System dynamic.**

**Presenting Author's biography**



Kodema Vyatcheslav Alexandrovich. I graduated from the Kola branch of the Petrozovodsky State University the faculty of Informatics and Applied Mathematics. At present, I am a first-year post-graduate student of the IIMM KSC RAS at speciality 05.13.18 – Mathematical modelling, numerical methods and program systems.

# 1 Introduction

The synthesis of the models of complex systems is the iterative process of «man-model» interaction during which both the model and the expert's knowledge are evolving. For developing the models of complex systems the expert's groups are involved. So the task of integration and accordance of knowledge is very important. Each expert has his own mental model of the system which is formed by him in some domain of base concepts which inheres his data domain. Hence, the problem of lack of terms accordance is raised. Also, because of the complexity of the systems the fuzzy knowledge about many parameters of the system is raised. As a result we have the problems with formalization of these systems.

The searching of ways of solving these problems led to appearing in 1960-th of specialized method of imitating modeling – of system dynamic [1, 3]. The method of system dynamic enables to investigate the behavior of complex systems. It is supported by the possibilities of computer simulation. In contrast to «traditional» methods of computer simulation the system dynamic doesn't require of building mathematical model of the model-based object in traditional form and gives investigator the tools for simulation in the form of UML-diagrams [2, 4]. As in case of complex systems the fuzzy knowledge about structure and composition of the model exists, then the synthesis of acceptable for practical usage dynamic model may takes for some years. Therefore the formalization and the automation of this process is the relevant task. As the apparatus for this the conceptual modeling is selected. The conceptual model is used for transition from expert's knowledge to their unified formal description. After that the formal synthesis of the system-dynamic model will be enabled.

For increasing the rate of developing the system-dynamic models is used the conceptual patterns technology. The conceptual pattern is the abstract uniformed model which covers the domain of particular models. The usage of the patterns also increases the correctness of the developing model.

The work is devoted to developing the synthesis' automation system which supplies the building of the system-dynamic models of complex systems by expert's group.

# 2 The synthesis' formalization

In formal description of the development system has been selected the following elements: the tree of aims, the patterns' set of the model, the reference book, and the informational and material relations.

## 2.1 Composition and structure of the system

*The tree of aims* contains the decomposition of global aim and material relations (more detail about material relations will be described below) between its elements taking into account the viewpoint of each expert on the problem.

*The patterns' set*. Under the pattern I will mind some construction which has established structure in time and sets of in and out parameters and initial values. In the work the pattern will be realized as construction on system dynamic language and the patterns' specification will be carried out took into account this factor.

The pattern concept formally may be presented by follow record on set theory language: P = {St, Fn, X, Y, I}, where St – the structure of the pattern, Fn – the law of the pattern functioning, X – the set of in pattern's parameters, Y – the set of out pattern's parameters, I – the set of initial pattern's values.

In the work the pattern considers as separate object which has its own internal structure. The object investigates as a "black box" which has its own in and out parameters and comprising some functional load (Fig. 1).

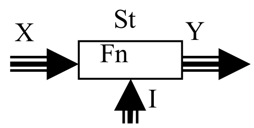



Fig. 1 Formal pattern presented as a "black box"

In the work it is necessary to differ the pattern that is defined by its specification from the one that defined by the initial pattern's values and is called *the reference*. Thus the reference of the pattern is the pattern filled properly, which contains the information not only about pattern's composition and structure but also it contains specific values of in, out and initial pattern's values and more over each reference is addressed by the expert to one of the tree of aims' primitives.

*The reference book*. This structure of data contains necessary, by experts' mind, information about data domain of model-based object. The information may be divided into two constituents: the conceptual-terminological one and the base of norms. In the conceptual-terminological part terms and concepts are defined, thereby the unification of the terminological apparatus is carried out. So the specialists of different fields using beforehand defined concepts and terms will interact on the one language. The set of terms and concepts is called V. The base of norms contains the supplemental information about different norms of data domain, for example different coefficients and constants. The set of norms and constants is called W.

*The informational relations between the references* are the relations which are instantly transmit the parameters' values from one reference to another. The informational relations communicate different elements of patterns' structures.

Under *material relations* I will mind the binding of separate references together through such elements of system dynamic as flows. The material relations define the integration's law of lower-level references into upper-level ones.

For the description of formal synthesis the follow set of procedures was developed:

1 The conclusion procedures which define for each model's pattern covering actions (the procedures of comparison).

2 The conclusion procedures which define the material relations between the patterns of the dynamic model.

3 The conclusion procedures which define the informational relations between the patterns of the dynamic model.

### 2.2 The conclusion procedures which describe the formal synthesis of the model

*1 The conclusion procedures $\omega_1$ and $\omega_2$ define for each model's pattern covering actions, i.e. how it is compared to the tree of aims' primitive.*

*1.1 The procedure of pattern's comparing to primitive.*

The function of this procedure is to realize the tree of aims' primitive's covering of the conceptual model by the pattern.

Let Tr is the tree of aims' vertexes' set of the conceptual model, $L \subset Tr$ – the set of leafs (primitives) and A – the set of all patterns. So the procedure $\omega_1$ may be defined as the mapping of primitives' set onto patterns' set.

$$\omega_1 : L \to A,$$

And $\forall\, l_i \in L\ \exists\, a_j \in A$: $f_i = Fn_j,\ i = \overline{1,m},\ j = \overline{1,k}$,

where $f_i$ – the primitive's aim,

$Fn_j$ – the aim of pattern's functioning,

m – the tree of aims' primitives' number of the conceptual model,

k – the patterns' number.

Thus the covering pattern exists for each primitive if the law of the pattern's functioning covers (satisfies) the aim(s) of the primitive.

Hence the process of covering is carried out on the base of the primitive's aim's functional covering by the pattern ($f_i$=$Fn_j$).

As a result we obtain the set of empty references G.

*1.2 The procedure of reference's defining.*

Let E – the set of all references in the model. The procedure $\omega_2$ in the general case may be presented as the mapping of empty references' set onto set of terms and norms.

$$\omega_2 : G \to V \cup W,$$

*And* $\forall\, g_i \in G\ \exists\, \overline{v} \subset V, \overline{w} \subset W : (\forall\, s \in St_i \to v \in \overline{v})\ \&$ $(\forall\, i \in I_i \to w \in \overline{w}),\quad i = \overline{1,n}$

where n – the number of the empty references in the system.

Thus for each empty reference from the set G there are such vectors $\overline{v} \subset V, \overline{w} \subset W$, that for each element of empty reference's structure will be found corresponding element of the set of concepts and terms V, and for each empty reference's initial value will be set the value from base of norms (the set of coefficients and constants W).

In other words the procedure of reference's defining implements the filling model's empty references by specific content which is obtained from supplemental information. As a result we obtain the model's references' set E.

*2 The conclusion procedures which define the material relations between the patterns of the dynamic model.*

In the work the pattern's reference is the system-dynamic model which has its own structure and composition, in and out parameters. As in and out pattern's parameters are the flows which can flow in/out other patterns.

In general case under condition that all primitives which has a pattern after filling becomes references the procedure $\varphi$ may be presented as the mapping of some references' subset onto product of the same subset by itself.

$$\varphi : E_1 \to E_1 \times E_1, \text{ где } E_1 \subset E,$$

And $\forall\, e_i \in E_1\ \exists\, e_j \in E_1$: $< e_i, e_j > \in E_1 \times E_1$, $i, j = \overline{1, n_k}$, $n_k$ – the number of references in $E_1$ ($n_k$<n).

Thus the mapping scheme $\varphi$ may be presented as the matrix $\varphi_k(n_k \times n_k)$, the rows and columns correspond to pattern's references of the model. The values of the matrix's elements are defined by the existence of the relations between the corresponding pattern's references of the model on the $k^{th}$ level of the hierarchy.

For setting formal relation between two references redefine standard definitions of the arithmetical operations: «+» - consecutive combination, «*» - parallel combination.

So the notation P = P1 + P2 means $\forall\, y_i \in Y_1\ \exists\, x_j \in X_2$: $y_i = x_j,\ i = \overline{1,m}, j = \overline{1,n}$, n – the in parameters' quantity of the pattern P2, m – the out parameters' quantity of the pattern P1, and n=m (in this case).

Define the matrix $\varphi_k(n_k \times n_k)$.

$$\varphi_k = \begin{cases} 2, \text{if } e_i * e_j \\ M_{ij}, \text{if } e_i + e_j \\ 0, \text{if } i = j \text{ or no relation between the patterns} \end{cases},$$

*where* $i, j = \overline{1, n_k}$

$e_i$, $e_j$ – patterns' references of $k^{th}$ level if the parent vertex is of $k+1^{th}$ level,

$M_{ij}$ – the matrix of coupling of in and out parameters of tow references.

In the trivial 1-D case when is supposed that each reference has one in and one out parameter so if the references have consecutive relation then current element of the matrix will be set to 1.

In multivariate case the element $M_{ij}$ also will be the matrix:

$$M_{ij} = B_{tp} = \begin{cases} 0, \text{if } y_t \neq x_p \\ 1, \text{if } y_t = x_p \end{cases}, \quad \text{where } t, p = \overline{1, m}$$

m – the quantity of references' in/out parameters.

Thus with the supporting of the upper mentioned procedure the material relationships among patterns' references of the model are established, i.e. relations that are determined by the flows.

*3 The conclusion procedures which define the informational relations between the patterns of the dynamic model.*

In the models of the system dynamic, excepting material relations realized through flows, informational relations are widespread and the main function of which is instantly transmit the information about values among model's elements.

In this work the three types of informational relations are considered, they are: the relations among structures' elements of two patterns' references, the relations among additional variables and structure's elements of the reference and the last one is the relation among structure's elements of the reference and additional variables.

*3.1 The conclusion procedure which define informational relations among structures' elements of two patterns' references.*

Let $E_1 \subset E$ is the subset of the references' set of the model and contains references which cover all child vertexes of the tree of aims' parent vertex $P_l^k$ (k – the level of hierarchy, l – the vertex's index at the level).

Thus mapping ψ may be presented as follows:

$$\psi: E_1 \to E_1 \times E_1,\ E_1 \subset E,$$

And $\exists\, e_i \in E_1\ \exists\, e_j \in E_1$:

1) $\langle e_i, e_j \rangle \in E_1 \times E_1$, $i, j = \overline{1, n_k}$, $n_k$ – quantity of references in $E_1$

2) $\exists\, s_p \in St_i \in e_i\ \exists\, s_t \in St_j \in e_j: \langle s_p, s_t \rangle \in St_i \times St_j \subset E_1 \times E_1$, where $t \in [1; m_i]$ and $p \in [1; m_j]$, $m_i$ and $m_j$ – quantity of structure's elements in the references $e_i$ and $e_j$ correspondingly.

The first statement says that between two references of the set $E_1$ the informational relation exists. The second one explains between which of them the relation is established.

Thus, in general case, the operator ψ may be presented as mapping of the references' set's subset onto product of it by itself with the pointing references' structure's elements among which ones the informational relation is established.

The scheme of mapping of the operator ψ may be presented as square matrix $\psi(n_k \times n_k)$, the rows and columns correspond to the elements of the set $E_1$. The values of the element of this matrix are defined by the existence of relation between corresponding references of the set.

$$\psi_{ij} = \begin{cases} B_{ij}, \text{if for } e_i \in E_1\ \exists\, e_j \in E_1 : \langle e_i, e_j \rangle \in E_1 \times E_1, \\ 0, \text{else} \end{cases}$$

$i, j = \overline{1, n_k}$

In one's turn the element $B_{ij}$ of the matrix $\psi(n_k \times n_k)$ also is the matrix $B(m_i \times m_j)$, where $m_i$ and $m_j$ – the quantity of the structure's elements of the references $e_i$ and $e_j$ correspondingly. The view of this matrix may be defined as follows:

$$B_{pt} = \begin{cases} 1, \text{if for } s_p \in St_i \in e_i\ \exists\, s_t \in St_j \in e_j : \langle s_p, s_t \rangle \in St_i \times St_j \\ 0, \text{else} \end{cases}$$

*3.2 The conclusion procedure which define informational relations among additional variables and structure's elements of the reference.*

This procedure is established as the mapping of additional variables' set Vk obtained as a result of adding experts' knowledge about the model-based object onto the product of this set and model's references' set $E_1$ which is the subset of all references' set E of the model.

In the process of practical works of developing system dynamic models on the base of patterns the fact that only patterns for developing of adequate model is not enough was revealed. In this cause were made decision about introducing in the conceptual model's knowledge base the additional variables' set. The main function of these objects is in the adding the model built on the base of patterns by experts' knowledge.

Let Vk – the set of the additional variables of the model and $E_1$ – references' subset of the model, then

$$R1: Vk \to Vk \times E_1,\ E_1 \subset E,$$

And $\forall\, v_i \in Vk\ \exists\, e_j \in E_1: \langle v_i, e_j \rangle \in Vk \times E_1$ (1)

$i = \overline{1,k}$, $j = \overline{1,n_k}$.

k – the quantity of the model's additional variables,

$n_k$ – quantity of references in $E_1$

Taking into account that each reference has its own internal structure and as a parameter of informational relation may be any element of the structure, i.e. $e_j = \{St_j, Fn_j, X_j, Y_j, I_j\}$ then the proposition (1) may be presented as follows:

$\forall\ v_i \in Vk\ \exists\ e_j \in E_1 |\ \exists\ s_k \in St_j: <v_i, s_k> \in Vk \times St_j \subset Vk \times E_1$

The scheme of mapping of the operator R1 may be presented as the matrix $R1(k \times n_k)$, the rows correspond to the elements of the additional elements' set Vk and the columns correspond to the elements of the set $E_1$. The values of the elements of this matrix are defined by the existence of the relation between corresponding elements of these sets.

$$R1_{ij} = \begin{cases} A_j, if\ \ for\ v_i \in Vk\ \exists\ e_j \in E_1 : < v_i, e_j > \in Vk \times E_1 \\ 0, else \end{cases}$$

In one's turn the element $A_j$ of the matrix $R1(k \times n_k)$ is the vector $A(m_j)$, where $m_j$ – the quantity of the structure's elements of the reference $e_j$. The view of this vector may be defined as follows:

$$A_t = \begin{cases} 1, if\ \ for\ v_i \in Vk\ \exists\ s_t \in St_j \in e_j : < v_i, s_t > \in Vk \times St_j \\ 0, else \end{cases}$$

*3.3 The conclusion procedure which define informational relations among structure's elements of the reference and additional variables.*

This procedure is established as the mapping of the model's references' set $E_1$ which is the subset of all references' set E of the model onto the product of this set and additional variables' set Vk of the model.

$$R2: E_1 \rightarrow E_1 \times Vk, E_1 \subset E,$$

And $\exists\ e_i \in E_1\ \exists\ v_j \in Vk: <e_i, v_j> \in E_1 \times Vk$, (2)

$i = \overline{1, n_k}$, $j = \overline{1, k}$.

$n_k$ – the quantity of references in $E_1$,

k – the quantity of additional variables in the model.

Taking into account that each reference has its own internal structure and as a parameter of informational relation may be any element of the structure, i.e. $e_j = \{St_j, Fn_j, X_j, Y_j, I_j\}$ then the proposition (2) may be presented as follows:

$\exists\ (e_i \in E_1 \mid \exists\ s_k \in St_i)\ \exists\ v_i \in Vk: <s_k, v_i> \in St_j \times Vk \subset E_1 \times Vk$

The scheme of mapping of the operator R2 may be presented as the matrix $R2(n_k \times k)$, the columns correspond to the elements of the additional elements' set Vk and the rows correspond to the elements of the set $E_1$. The values of the elements of this matrix are defined by the existence of the relation between corresponding elements of these sets.

$$R2_{ij} = \begin{cases} C_i, if\ \ for\ e_i \in E_1\ \exists\ v_j \in Vk : < e_i, v_j > \in E_1 \times Vk \\ 0, else \end{cases}$$

In one's turn the element $C_i$ of the matrix $R2(k \times n_k)$ is the vector $C(m_i)$, where $m_i$ – the quantity of the structure's elements of the reference $e_j$. The view of this vector may be defined as follows:

$$C_t = \begin{cases} 1, if\ \ for\ s_t \in St_i \in e_i\ \exists\ v_j \in Vk : < s_t, v_j > \in St_i \times Vk \\ 0, else \end{cases}$$

Using of this procedures provide the formal synthesis of the composition and structure of the dynamic model which is satisfied to developed conceptual model of researching data domain. The sequence of using the procedures established by the synthesis' algorithm of the system dynamic model based on the pattern's technology.

## 3 The synthesis' automation tools

The synthesis' automation system consists of:

1 The system's knowledge base;

2 The block of user interface;

3 The block of experts' knowledge formalization;

4 The block of patterns' forming;

5 The block of patterns' comparison;

6 The block of model synthesis.

The system's knowledge base is the computer representation of the formalized experts' knowledge about the data domain and realized as six main tables into database:

1 The tree of aims' table;

2 The table of patterns' specifications;

3 The table of patterns' references;

4 The table of informational relations;

5 The table of reference book;

6 The table of additional variables.

*The block of user interface* is the set of programs which supplies the comfortable interaction of user and system. The programs of user interface serve all functions of the system which realize the information exchange with a user.

*The block of experts' knowledge formalization* is the block of forming the conceptual model's common structure and private subsets of experts. This is the software package which supplies the development and realization of the conceptual model of data domain based on experts' knowledge as a knowledge base. The programs of this block execute the system setting on the researching data domain with the aim and composition establishing, developing of experts variants of conceptual model decomposition as a personal knowledge bases and synthesis on their base of final variant of knowledge base which is the setting of conceptual model's relations as the relations among personal knowledge bases.

*The block of patterns' forming* is the software package which allows experts to realize the patterns with the actions such as: adding, editing and deleting a pattern.

*The block of patterns' comparison* is the software package which allows experts to compare developed patterns to their primitives, i.e. it allows them to develop patterns' references.

*The block of model synthesis* is the software package which allows a system analyst to realize the synthesis of final developed conceptual model.

## 4 Conclusion

During my work I developed the conclusion procedures and synthesis algorithm of system dynamic models which is based on them. The algorithm supplies the aggregation of collective experts' knowledge which is formalized as a conceptual model.

I also developed the synthesis' automation system of system dynamic models. The system solves the follow main tasks: organization of dialog with a user, acquisition and replenishment of knowledge, realization of the patterns, patterns' comparison and synthesis of the data domain's model.

The effectiveness of the system was demonstrated on developing of the system dynamic model of fuel and energy complex of Murmansk region.

At present I work at integrating of pattern recognition system in order to increase the satisfaction of comparison of patterns and experts' primitives and to decrease the working load of experts.

## 5 References

[1] R. Shennon. Imitating modeling of the systems. 1978. – 418p.

[2] G. Buch, J. Rambo, A. Jecobson. The UML language. User guide. 2004. – 429p.

[3] U. N. Pavlovskiy. Imitating models and systems. 2000. – 134p.

[4] Powersim 2.5 Reference Manual .-Herndon, USA: Powersim Press, 1996.- 427p.

ISBN 978-3-901608-32-2