Calculation of the Function Objects as the Systems Formal Theory Basis

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Abstract. The paper deals with the conceptual foundations of functional objects calculus as a formal theory of systems. The basic concepts and definitions of the calculus of functional objects are presented, within the framework of which the functional object is considered as a system described in terms of the systemic-object approach "Unit-Function-Object". The authors introduce a number of basic definitions and operations on functional objects, that are: adding, deleting the fields of a streaming object within the calculus; redefining of fields; redefining the methods of unit objects; connections of unit objects according to various criteria.

Keywords: System-object modeling technology "Node-Function-Object" · Simulation modeling · Formal representation of the organizational system · System approach · Simulation of the functioning of the process · System-object method of representation of knowledge

1 Introduction

At present, there are no methods of computer representation of knowledge that would allow to create universal subject modeling tools for efficient intellectual management of complex technological processes and robotic systems. In this regard, it makes sense to set the task of creating a universal method of knowledge representation in computer information systems by using, for example, the systemic approach "Unit-Function-Object" (UFO-approach) [1], providing a universal approach to the systems of different nature. By solving this problem it'll become possible to develop automated control systems and decision support systems using artificial intelligence methods to establish automate technological processes and industries, to ensure the competitiveness, safety, eco-friendliness and efficiency of the domestic industry.

Due to the fact that if create a universal method for representation of knowledge it is necessary to provide the possibility of representing all types of knowledge using a single universal means, it is proposed to use the systemic-objective method of

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knowledge representation (SOMKR) as a tool for creating a universal method of representing knowledge of the subject area [2]. This method is designed specifically for modeling the poorly formalized areas of human knowledge. The use of the proposed method for knowledge representation for the purpose of managing technological processes is due to the following considerations. The subject area, which a complex technological process is car-ried out within, is itself a complex system. Therefore, knowledge about this subject area should also be formed out in a form of system. Analysis of the knowledge types reviewed in the literature on artificial intelligence and knowledge management presents that all types of knowledge can be differentiated to three basic types: declarative knowledge of the structural characteristics of the system (at the input-output level), procedural knowledge (on the dynamics of its functioning), declarative knowledge of the substance of the system (about the object performing the function). SOMKR, based on the UFO approach, in its turn, is a universal means of describing organizational knowledge, as it allows one to describe in one model both object characteristics, and structural characteristics, and the functional characteristics of the simulated system. Information system based on this method of representing organizational knowledge allows to store and process the experience of the organization in a convenient visual (graphoanalytical) and at the same time formalized form.

The developed systemic-objective method of knowledge representation has a number of significant advantages [2]. It is the authors` opinion that, for example, a possibility of graphical knowledge representation, a possibility of graphical representation to a simulation model conversion, and a possibility of these graphic representations formalization belong to such advantages [2]. However the last opportunity, according to the authors, is poorly implemented, leading to the need for the pursuance of an additional research, namely to the solution of the problem of system-object approach «Unit-Function-Object» (UFO-approach) larger formalization [3]. We will consider one of this approach formalization variant which is used by authors for the formalized system theory creation.

2 Basic Concepts and Definitions

The conceptual framework of the systems approach is given below (in more detail [4]). Based on this framework the formal constructions of calculation, underpinning the system theory, will be described further. Firstly, the system is considered as the functional object which function is caused by higher tier object function (i.e. supersystem) [5]. Secondly, any system is definitely connected with other systems and these communications represent flows of the related systems deep tier elements [5]. At the same time communications of this system with other systems – functional, connections between this system subsystems – supporting. Thirdly, a consequence of the abovementioned system definition and understanding of communication between systems is a representation of system in the form of triune construction «Unit-Function-Object» (UFO-element) where:

- unit - structural element of supersystem in the form of the this system communications intersection with other systems;

- function - the dynamic (functional) supersystem element, fulfilling a certain role from the perspective of maintenance of a supersystem by this unit communications balancing;
- object - substantive supersystem element, realizing this function in terms of some material formation possessing constructive, operational characteristics.

Earlier authors conducted researches on formalization of system- object approach with use of the Grenander patterns theory and the Milner processes calculation. However, the full-fledged description of systems as «Unit-Function-Object» elements with their help was unable to obtain. At the moment the most perspective for formalization of UFO approach occurs the ideas, embodied in Abadi-Cardelli objects calculation [6]. The understanding and wording of the abstract object in this calculation allowed when developing SOMKR to offer the formal description of an UFO element as special "nodal" object, and also the formal description of communication as special "stream" object [7, 8]. These formalisms are used further when constructing the function objects calculation, i.e. calculations of systems as UFO elements.

For creation of mentioned calculation we will introduce to the consideration the L streaming objects set corresponding to system communications set.

$$L = \{l_1, l_2, \ldots, l_n\}, \tag{1}$$

where n – quantity of streaming objects (communications of system).

Every n-element of L set represents a special streaming object (corresponding to a system specific communication) which, according to Abadi-Cardelli objects theory, consists of fields, doesn't include methods and has the following appearance:

$$l_n = \left[r^1, r^2, \ldots, r^k\right], \tag{2}$$

where $l_n \in L$; k – quantity of streaming object l_n fields; r^1, r^2,...,r^k – the streaming object field, representing the couple «identifier – meaning».

The L set in so doing will take the following form:

$$L = \left\{l_1 = \left[r_1^1, r_1^2, \ldots, r_1^{k1}\right], l_2 = \left[r_2^1, r_2^2, \ldots, r_2^{k2}\right], \ldots, l_n = \left[r_n^1, r_n^2, \ldots, r_n^{kn}\right]\right\}, \tag{3}$$

where the suffix numbers of the r fields are the number of the streaming object-parent, and their fields super scripts are the ordinal number of the field within the parent streaming object, and k_n is the number of fields of the streaming object l_n. Denote the set of fields of the streaming object l_n by the var R_n, then:

$$R_n = \left\{r_n^{kn} | r_n^{kn} = [identifier, meaning]\right\} \tag{4}$$

Thus, the L set of streaming objects (system communications) can be defined as follows:

$$L = \{l_n | l_n = [R_n]\} \quad (5)$$

Further we will introduce to the consideration a nodal objects S set, which corresponds to the systems set as an UFO-elements according to SOMKR framework [9, 10].

$$S = \{s_1, s_2, \ldots, s_j, \ldots, s_m\}, \quad (6)$$

where m – quantity of nodal objects (system).

Each m-element of S set represents a special nodal object (corresponding to a specific system /UFO-element) which, according to Abadi-Cardelli objects theory, consists of fields and a method and has the following appearance:

$$s_m = [U, f, O], \quad (7)$$

where U is a set of fields for the description of the interface streaming objects of a nodal object s_m, corresponding to a set of this system functional communications.

Set $U = L_? \cup L_!$, where $L_?$ – is a set of the input interface streaming objects corresponding to the input system communications, $L_!$– is a set of the output interface streaming objects, corresponding to the output system communications. Indexes "*?*" and "*!*" of the streaming objects during the work are used as the designation of the incoming "*?*" and the outgoing "*!*" of the streaming object in relation to the unit object (see Fig. 1). Whereby: $L_? \subset L$; $L_! \subset L$. F is a method of a nodal object s_m, describing a conversion function of the input interface streaming objects (the incoming system communications) $L_?$ in output - $L_!$. Further we will present the method of a nodal object in the following form:

$$f(L_?)L_!, \quad (8)$$

where f – is the method of a nodal object (system function) with the range of definition $L_?$ and the range of values $L_!$, thereafter.

O - is a fields set for the description of object characteristics of a nodal object (system) s_m, which elements have the following format:

$$O = \{o_i | o_i = [identifier, meaning]\}, \quad (9)$$

where i is the number of fields of the unit object s_m. The set of fields for the description of system object characteristics consists of three subsets:

$$O = O_? \cup O_! \cup O_f \quad (10)$$

Set of fields $O_?$ contains interface input characteristics of the nodal object. There is an appropriate sample of a kind for each field of each input streaming object in $O_?$ set (9). Thus, if, for example, the set of the input streaming objects consists of one element (a stream object l_1), and the set of fields of the input streaming object consists of two elements of the following appearance:

$$L_? = \{l_1 = [r_1, r_2]\}, \tag{11}$$

then appropriate $O_?$ set will take a form:

$$O_? = \{o_1, o_2\} \tag{12}$$

Potency of $O_?$ set will depend on quantity of the input interface streaming objects and their fields quantity. If the potency of set:

$$|L_?| = n, \tag{13}$$

and capacities of input streaming objects:

$$\left|l_?^1\right| = m_1, \left|l_?^2\right| = m_2, \ldots, \left|l_?^n\right| = m_n, \tag{14}$$

then the potency of corresponding set of object $O_?$ interface characteristics will be equal:

$$|O_?| = \sum_1^n |l_?^n| \tag{15}$$

The potency of $O_!$ set (corresponds to output interface streaming objects), by analogy with the expression (15) is calculated upon the formula:

$$|O_!| = \sum_1^n |l_!^n| \tag{16}$$

O_f set contains the system object characteristics, inherent in the object realizing function, and their quantity will depend on specific system.

Thus, we will present the system within systems calculation described by expression (7) in the form of the following expression:

$$s_m = \left[L_?, L_!; f(L_?)L_!; O_?, O_!, O_f\right] \tag{17}$$

Graphical presentation of expression (17) is shown in a Fig. 1. We will consider this presentation as a graphic formalism, by analogy with graphic formalism-generatrix – in the Grenander patterns theory. This non-derivative object will be the elementary data carrier in our calculation.

Further we will consider elementary operations on the defined above sets of streaming and nodal objects by means of which in the long term the possibility of the computation organization within the developed formal system theory will be provided.

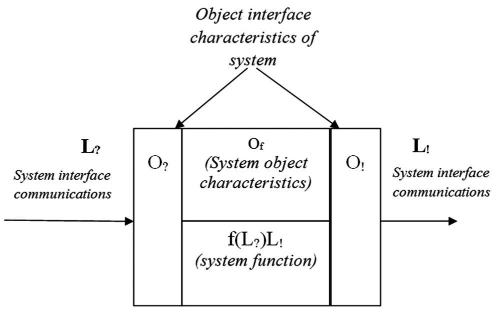

Fig. 1. Graphical formalism of system as UFO-element

3 Operations with the Function Objects

We will enter into our calculation elementary structural operations on L streaming objects sets and nodal objects S. As elementary operations on set of streaming objects, the operations given below are offered.

3.1 r_0 Field to a Streaming Object l Adding Operation

Let there be given a streaming object $l = [R]$, where $R = \{r_1, r_2,\ldots,r_k\}$ and r_0 field for which is fair $\{r_0\} = R_0$. Then operation of adding of new field r_0 to a streaming object l will correspond to union of sets R and R_0. We denote this operation by the symbol ">>>", and in the left part of the operator we write a new field $l.r_0$ in terms of the calculus of the Abadi-Cardelli's objects, and in the right part we write the identifier of the streaming object l, then:

$$l.r_0 >>> l = [r_1, r_2, \ldots, r_k] \rightarrow l^* = [r_0, r_1, r_2, \ldots, r_{k+1}] \quad (18)$$

3.2 r_0 Field from a Streaming Object l Deleting Operation

Let there be given the streaming object $l = [R]$, where $R = \{r_0, r_1, r_2,\ldots,r_k\}$ and the r_0 field, for which is fair $\{r_0\} = R_0$. Then the result of operation of deleting the r_0 field from a stream object l will correspond to a set difference R and R_0. Applying the above – mentioned designations, we will receive. We denote this operation by the symbol "<<<", and in the left part of the operator we write the deleted field $l.r_0$ in terms of the calculus of the Abadi-Cardelli's objects, and in the right part we write the identifier of the streaming object l, then:

$$l.r_0 <<< l = [r_0, r_1, r_2, \ldots, r_k] \rightarrow l^* = [r_1, r_2, \ldots, r_{k-1}] \quad (19)$$

3.3 The Streaming Object *l* r_0 Field Redefinition Operation

Let there be given the streaming object $l = [R]$, where $R = \{r_0, r_1, r_2, \ldots, r_k\}$ and the $r_0$field for is fair $\{r_0\} = R_0$, and also the r_0* field, for which is fair $\{r_0*\} = R_0*$. Then the result of operation of streaming object l r_0 field redefinition will correspond a set R_0 * with R and R_0 set difference combining:

$$l.r_0 \Leftarrow l = [r_0, r_1, r_2, \ldots, r_k] \rightarrow l^* = [r_0^*, r_1, r_2, \ldots, r_k] \tag{20}$$

3.4 Nodal Object *s* Method *f* Redefinition Operation

Let there be given a nodal object $s = [U, f, O]$, where $U = L_? \cup L_!$, $f(L_?)L_!$ and method $f^*(L_?^*)L_!^*$, for which $L_?^* \subset U$ and $L_!^* \subset U$. Then the result redefinition operation of method f in object s will be defined by analogy with similar operation in Abadi-Cardelli objects theory by the following expression:

$$s.f \Leftarrow f(L_?)L_! \rightarrow f^*(L_?^*)L_!^* \tag{21}$$

3.5 The Operation of Connecting Objects of a Unit

Two objects s_i and s_j are given that:

$$s_i = [L_{?i}, L_{!i}; f(L_{?i})L_{!i}; O_{?i}, O_{!i}, O_{fi}];\ s_j = [L_{?j}, L_{!j}; f(L_{?j})L_{!j}; O_{?j}, O_{!j}, O_{fj}] \tag{22}$$

The rule for redefining the fields and the method of the object j in case of attaching this object to the object i- call for the method of the object j by the object i:

$$s_j.f \rightarrow L_{!j}\{L_{!i} \rightarrow L_{?j}|s_j\}, \tag{23}$$

if $L_{?j} \equiv L_{!i}$ and $O_{?j} R O_{!i}$, is reduced to the following expression:

$$s_j.f \Leftarrow f(L_{?j})L_{!j} \rightarrow f(L_{?i})L_{!j};\ L_{?j} \rightarrow L_{?i};\ O_{?j} \rightarrow O_{?i}, O_{fij} \tag{24}$$

We get the object (see Fig. 2):

$$s_{ij} = [L_{?i}, L_{!j}; f(L_{?i})L_{!j}; (O_{?i},\ O_{!j},\ O_{fij})] \tag{25}$$

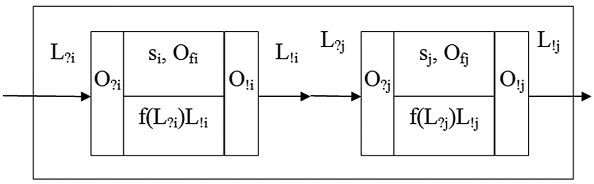

Fig. 2. The operation of connecting objects of a unit

The rule for redefining the fields and method of the object i in case of attaching this object to the object j- call for the method of the object i with the object j:

$$s_i.f \to L_{!i}\{L_{!j} \to L_{?i}| \to s_i\}, \tag{26}$$

if $L_{?i} \equiv L_{!j}$ and $O_{?i} R O_{!j}$, is reduced to the following expression:

$$s_i.f \Leftarrow f(L_{?i})L_{!i} \to f\left(L_{?j}\right)L_{!i}; L_{?i} \to L_{?j}; O_{?i} \to O_{?j}, O_{fji} \tag{27}$$

We get the object:

$$s_{ji} = \left[L_{?j}, L_{!i}; f\left(L_{?j}\right)L_{!i}; \left(O_{?j}, O_{!i}, O_{fji}\right)\right] \tag{28}$$

3.6 Joining Objects by Input

Two objects s_i and s_j are given, with $L_{?i} \equiv L_{?j}$ and $O_{?i} = O_{?j}$. The rule for redefining fields and methods in this case is reduced to the following two options:

$$s_i.f \Leftarrow f(L_{?i})L_{!i} \to f(L_{?i})L_{!i}, L_{!j}; L_{!j}; O_{!j}, O_{fij} \tag{29}$$

$$s_j.f \Leftarrow f\left(L_{?j}\right)L_{!j} \to f(L_{?i})L_{!i}, L_{!j}; L_{?j} \to L_{?i}; L_{!i}; O_{?j} \to O_{?i}; O_{!i}, O_{fij} \tag{30}$$

Regardless of the variant, we get the object (see Fig. 3):

$$s_{ij} = \left[L_{?i}, L_{!i}, L_{!j}; f(L_{?i})L_{!i}, L_{!j}; \left(O_{?i},\ O_{!i},\ O_{!j},\ O_{fij}\right)\right] \tag{31}$$

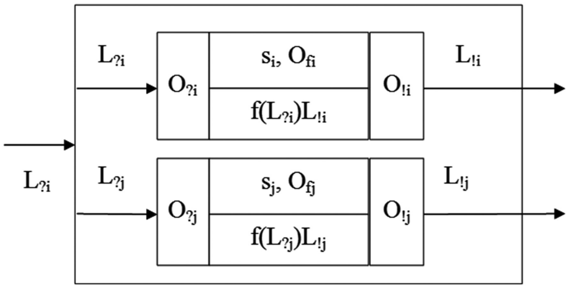

Fig. 3. Joining objects by input

3.7 Joining Objects by Output

Two objects s_i and s_j are given, with $L_{!i} \equiv L_{!j}$ and $O_{!i} = O_{!j}$. The rule for redefining fields and methods in this case is reduced to the following two options:

$$s_i.f \Leftarrow f(L?_i)L!_i \to f\left(L_{?i}, L_{?j}\right)L_{!i}; L_{?j}; O_{?j}, O_{fij} \quad (32)$$

$$s_j.f \Leftarrow f\left(L?_j\right)L!_j \to f\left(L_{?i}, L_{?j}\right)L_{!i}; L_{?i}; L_{!j} \to L_{!i}; O_{!j} \to O_{!i}, O_{fij} \quad (33)$$

Regardless of the variant, we get the object (see Fig. 4):

$$s_{ij} = \left[L_{?i}, L_{?j}, L_{!i}; f\left(L_{?i}, L_{?j}\right)L_{!i}; \left(O_{?i},\ O_{?j},\ O_{!i},\ O_{fij}\right)\right] \quad (34)$$

The three operations described (that are: connecting objects, joining objects by input and joining objects by output) are considered as basic operations of the proposed calculus. They correspond to the three structural phenomena and three kinds of objects, which any structure and system of any complexity can be created of: simple flow (simple object), merge of flows (object of merging) and branching of flow (object of branching). As a matter of fact, these operations are reduced to describing the image obtained by building a configuration from non-derivative objects (graphic formalisms) and describing non-closed connections.

All other interactions of UFO-elements as special objects can be obtained by combining basic operations.

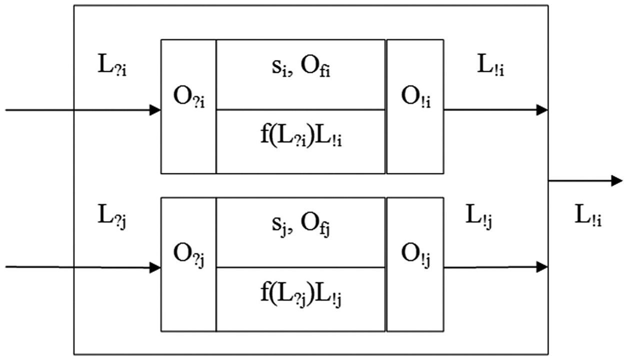

Fig. 4. Joining objects by output

4 Findings and Conclusions

In this work the possibility of system-object approach "Unit-Function-Object" formalization and based on it system-object method of organizational knowledge representation is investigated. The feasibility of use for this Abadi-Cardelli objects calculation and some ideas of the Grenander patterns theory are shown. In terms of the mentioned calculation a special object, representing system as an UFO-element, and corresponding to it graphical presentation are formulated. By means of the provided elementary operations there is an opportunity to build more complex operators of streaming and nodal objects processing within this calculation. In the long term similar operators will allow to build algorithms of automatic constructing of systems models in the form of nodal and streaming objects combinations. Besides, the received results show the feasibility of formalized system theory creation by extension and enhancement of special objects calculation as systems within UFO approach. One of the key are as for further development of the calculus of functional objects is the development of formal tools of description of the unit objects methods, as it is to determine the change of the incoming streaming objects into the outgoing. Development of a formal apparatus that allows to determine unambiguously the functioning of the system, would let the construction of a system models reflecting both static and dynamic indicators, determining states of the system, changing states in time, and so on.

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