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Intellectual Structural-parametric Synthesis of Large Discrete Systems with Specified Behavior

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Abstract: The relevant problem of the structural-parametric synthesis of large discrete systems with a specified behavior assuming the translation of a given input signal into the required reference output signal through intermediate states of the system is studied herein. In order to solve the time-consuming task of synthesizing this kind of systems, a combined approach is proposed that is based on the use of evolutionary methods, the mathematical apparatus of petri nets and simulation modeling. The study presents a model of an adapted genetic algorithm, making it possible to perform a procedure of both structural and parametric synthesis of large discrete systems with a specified behavior. Also, the use of binary trees for the purposes of representation of the elements and the interelement links in the genotype describing the model of a large discrete system with a specified behavior is suggested which makes it possible to apply genetic programming in solving the problem of structural and parametric synthesis of large discrete systems. The computational experiments carried out using the constructed model and the developed software and the models of the element base on the basis of the petri net theory, presented herein, testify to the effectiveness of the proposed procedure for the structural-parametric synthesis of large discrete systems with a specified behavior. Also, the possibility of using the parallel computations that will reduce the time of synthesis of the models of projected systems is considered in this scientific paper. The presented calculations made using the Amdahl law show how the response rate changes with the increase in the number of computers in solving the problem of structural-parametric synthesis of large discrete systems on the basis of the proposed approach.

Key words: System analysis, structural-parametric synthesis of large discrete systems, evolutionary algorithms, genetic algorithm, petri nets, simulation modeling

INTRODUCTION

The structural-parametric synthesis of Large Discrete Systems with a Specific Behavior (LDSSB) is a variation of a more general scientific and practical problem: the synthesis of systems with a specific behavior that are able to convert a given input vector (data, matter, energy, etc.) into the desired output vector (Lomazov *et al*., 2016; Ryzhikov and Semenkin, 2013; Sibani and Jensen, 2013) in which case the occurence of the situations when the system must pass through the predetermined states is possible.

For the purposes of development of the methodological apparatus of the structural-parametric synthesis of LDSSB, it is required to:

- Create the models and methods, making it possible to form the structure of the synthesized LDSSB
- Kreate the models and methods that will make it possible to synthesize the parameters of the functioning of the elements of the LDSSB structure
- Develop a single apparatus for describing the processes of structural and parametric synthesis of LDSSB

The models and methods that make it possible to solve the problem of structural-parametric synthesis of large discrete systems with a specific behavior, based on three modern theories: simulation modelling, evolutionary methods and the theory of petri nets are presented herein. The application of these apparatus to the solution of the

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problem of structural-parametric synthesis is due to the fact that most of the problems in this area can be attributed to the class of multicriterial and multiextremal ones, that is in addition to a large number of factors that affect both the decision itself and its course, the existence of more than one solution, satisfying the synthesis criteria is possible. It should be noted that when solving this class of problems, the attention is paid to both the structure of the system, the totality of the elements and the relationships between them and the search for settings of the operating modes of the system elements in the possible range of functioning. The solution to the tasks of this kind is rather time consuming; therefore, for their solution, the methods of casual search are applied in which the elements of determinism are introduced. The most suitable for this are the evolutionary methods (Gladkov *et al*., 2006; Eiben *et al*., 1994; Hingston *et al*., 2008).

Currently, one of the methods that have proved themselves quite well in solving the problems of synthesis, optimization and modeling by random selection, combination and variations of the desired structures and parameters is the Genetic Algorithm (GA). Its application will allow reducing the time of synthesis of the configuration of a large discrete system when working not only with changing the elements of the system but also with changing the settings of the elements that make up the system model.

GA requires the adaptation to the field of its application in our case, it is the structural-parametric synthesis of large discrete systems. Therefore, much attention should be paid to the apparatus for describing the models of synthesized systems, that is, the mathematical apparatus able to take into account the possibilities of parallelism of processes occurring in the system being synthesized as well as to possess both the property of determinism and the stochasticity property. It should not be forgotten that in the structural synthesis of a large discrete system, special attention should be given to describing the structure of a large discrete system obtained as a result of synthesis. The theory of petri nets is the mathematical apparatus making it possible to take into account all the above-described requirements. This mathematical apparatus, like the GA has a property of parallelism which makes it possible to adapt to the subject domain and among its extensions there are so-called embedded petri nets that allow the use of marks as a set. The apparatus chosen by the author have a property of parallelism, therefore, it will be expedient to perform the calculations that will show the expediency of application of the parallel computations at the use of the proposed models.

MATERIALS AND METHODS

Genetic algorithms: The GA, selected as an instrumental algorithm, implementing the process of structural-parametric synthesis, reflects the principles of natural selection, that is, the survival of the most promising individuals, the inheritance and mutation. This apparatus makes it possible to customize the work of its operators (breeding, crossing, mutation and reduction), which allows influencing the speed of synthesis of the models that meet the search criteria (Sibani and Jensen, 2013; Gladkov *et al*., 2006; Eiben *et al*., 1994; Hingston *et al*., 2008).

The elitism strategy can be applied in the work of the genetic algorithm which allows the transition of the best chromosome from one generation of the population to another without changes; this ensures the support for a high level of quality of the population (Hingston *et al*., 2008; Schmitt, 2001; Tsaregorodtsev, 2005, 2008; Peterson, 1981; Dawis *et al*., 2001).

The application and adaptation of genetic algorithms in various subject areas. The GA is a strategic approach and requires the adaptation to a specific subject area. Let us consider one of the main problems that arise in the adaptation the coding of the chromosome. The convergence and the speed of the genetic algorithm depends on the correct coding the stability.

At this stage, it should be understood that, based on the subject area, the length of chromosomes should be the same, since, different systems can have different number of elements and connections between them and the work of the operators of the genetic algorithm can result in the appearance of non-existent in nature models of systems. Therefore, a repeat bit must be allowed in the code string, that is, to re-write the elements and links for equalizing the length of the chromosome but at the stage of the computational experiment, this element will not get into the LDSSB Model on the basis of the petri net.

For each element that will participate in the structural-parametric synthesis of LDSSB, it is required to encode each of the elements using a binary tree with the branches of the same length, since, the number of bits for each of the elements must be the same. The use of a binary tree is also due to the fact that in genetic algorithms it is possible to use this representation of chromosomes and also that as a result of movement along the branches of this type of tree it is possible to form a binary code.

Since, the number of elements we have is three, the number of bits required is two. Therefore, the situation is possible in which one branch of the binary tree does not make sense, it is not permissible, then we should duplicate

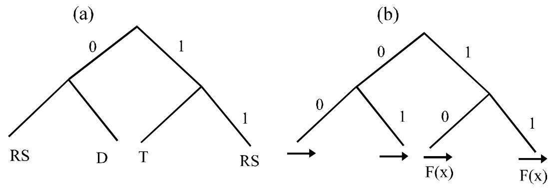

Fig. 1: a and b) Eexample of coding the elements and links using a binary tree

one component in the tree again (the RS component on the branch as shown in Fig. 1a. When composing a tree, the complexity of the element should be taken into account, i.e., the expert places them from simple to complex from left to right. This approach can be useful in assessing the population. Repeating the element makes it possible to prevent a situation in which a record [1 1] appears in the code line at the place of the element which will not make sense, that is such an element does not exist in the component database.

By the same principle, let us construct a binary tree for the intercomponent links (Fig. 1b). Proceeding from the proposed rule, the simplest connection is the ordinary arc, the code [0 0], the inhibitory arc is a more complex connection and has the code [0 1], the ordinary arc having the function is more complicated than the previous two and has the code [0 1] and the most complex connection is the inhibitory arc with a function, it has the code [1 1]. In this example, it is shown how the chromosome should be encoded by binary trees.

For a complete description of the chromosome in solving the problem of structural-parametric synthesis, the following trees should be created) the tree of elements) the tree of intercomponent links (the layer of intercomponent bus with the inclusion of the connection types and the elements) the parameter tree of the elements.

If an element or a link or a parameter is not used, then a control bit should be set before it which tells about it when restoring the network from the code string. Thus, the binary string for the genetic algorithm will have the same length and will always make sense.

Applications of petri nets for the description of genetic algorithms. When implementing the genetic algorithm by petri nets, one should take into account that more than one level of the network will be required. The upper level should describe the work of the genetic algorithm itself and the lower levels should contain the models of synthesized LDSSB. Therefore, from the whole variety of extensions of Petri nets, one should choose one that will support) independence of the domain) parallelism) probability and determinism) structural) multi-level nature.

Such an extension is embedded petri nets. In this extension, the marks of each level can be represented by the petri net which allows describing LDSSB with models of different nesting.

RESULTS AND DISCUSSION

Statement of the task: Let us consider the following class of tasks of the structural-parametric synthesis of LDSSB. It is given:

$$S = \langle \text{Input}, C, O_f, MK, T_f, ..., M, \text{Output} \rangle$$

Where:

S = LDSSB the synthesis of which should be performed, input is the inputs of LDSSB
Output = The outputs of LDSSB
C = The elements included in the LDSSB
O_f = The C_i element connections whose functions affect the performance parameter
MK = The element of the intercomponent bus of the S system
T_f = The functional components of the elements C_i and MK_i whose values affect the parameter of their functioning
M = The initial state of the C_i elements of the S system

Let us write down the elements included in LDSSB:

$$C = (C_1, C_R)$$

Where:

C_i = The ith component of a large discrete system
R = The number of LDSSB components

$$C_i = \{C_{ij}\}_{j=1}^{M_i}$$

Where:

C_{ij} = The jth copy of the ith component
M_i = The number of copies of the ith component

$$P = \{P_k\}_{k=1}^{L}$$

Where:

P = The set of properties that a synthesized large discrete system with a given behavior can possess
P_k = The kth property of the set P
L = The number of properties of the set P

Let us write down the links of the system:

$$O = (O_1, ..., O_R)$$
$$O_i = \{O_{ij}\}_{j=1}^{M_i}$$
$$O_{ij} = \langle TypeO_{start}, NE_{start}, N_{outstart}, TypeO, NE_{end}, N_{inend} \rangle$$

Where:

$TypeO_{start}$ = The Type of the link of the arc
Ne_{start} = The Number of the element from which the link comes out (should be determined by the sequence number of the element
C_i = The number of the inter-component bus element Mk_i)
$Nout_{start}$ = The output number of the element from which the link comes out
TypeO = The Type of the link
Ne_{end} = The Number of the final element for communication must be determined by the sequence number of the element C_i or the number of the inter-component bus element Mk_i)
Nin_{end} = The element input number C_i or the entry number of the inter-component bus element MK_i

Let us write down the inter-component bus elements:

$$MK = \langle TypeMK, \langle TypeMK_f \rangle \rangle$$

Where:

TypeMK = The inter-component type
T_{MKf} = The component of an inter-component bus element

The value of which affects its operation (is not taken into account in encoding). Let us, write down the functional components of the elements C_i and MK_i whose values affect the parameter of their functioning:

$$T_f = \langle TypeE, \langle T_{E_f} \rangle \rangle$$

Where:

TypeE = The Type of the Element
T_{E_f} = The component of the element, the value of which affects its functioning (is not taken into account when encoding)

$$M = \langle TypeE, \langle M_0 \rangle$$

Where:

TypeE = The Type of the Element
M_0 = The initial state of the Element

It is required: for a given behavior that LDSSB S should have, select one copy of each component of C_i and its operation parameter so that the large discrete system has a specified behavior.

Solution of the problem: To solve the problem of structural-parametric synthesis, it is required to prepare the element base for component models based on petri nets. In these models, highlight the functional arcs and transitions that affect the operation of the element model. Select the possible initial markings for each element that will display the initial state of the element that is part of the system being synthesized.

After preparing the model of the elements, the following binary trees should be constructed a binary tree for a set of C elements that can be part of the LDSSB a binary tree of the functional links of which affect the parameter C_i functioning in particular and the entire system S as a whole the binary tree elements of the intercomponent bus MK which can be a part of the LDSSB S, the binary tree of the functional transitions Tf of the elements C_i and MK_i, the value of which affect the parameter of the element functioning in particular and the system as a whole the binary A tree reflecting the possible initial states M (initial markings of element models based on petri nets) of the elements C_i and MK_i whose initial state affects both the operation of the elements C_i and the parameter of the functioning of the system S.

After this, the chromosome formation of the initial population is performed in the form of a binary code string which in turn can be deployed to the petri net due to the matrices P/T, T/P and M0. The objective function can be calculated by the degree of ensuring the required resultant response of the LDSSB the degree to which the given behavior is provided.

To do this, it is required to specify a number of input vectors and a series of output vectors as well as the intermediate states for the synthesized LDSSB. To estimate the proximity to the desired solution, one can use the hamming distance and a tree or graph of achievable markings (from which it will be possible to track whether the model passes through the required states). You can also use the penalty function.

The structure-parametric synthesis will be performed by the Petri net of the following type (Fig. 2). Such models in the general petri net will be four, for structural synthesis the synthesis based on LDSSB elements the synthesis on the basis of intercomponent bus. For parametric synthesis the synthesis on the basis of functional compounds and transitions the synthesis on the basis of the initial states of the LDSSB elements. Each of the four models of the genetic algorithm for processing the population of the LDSSB models can be run both separately and in combination.

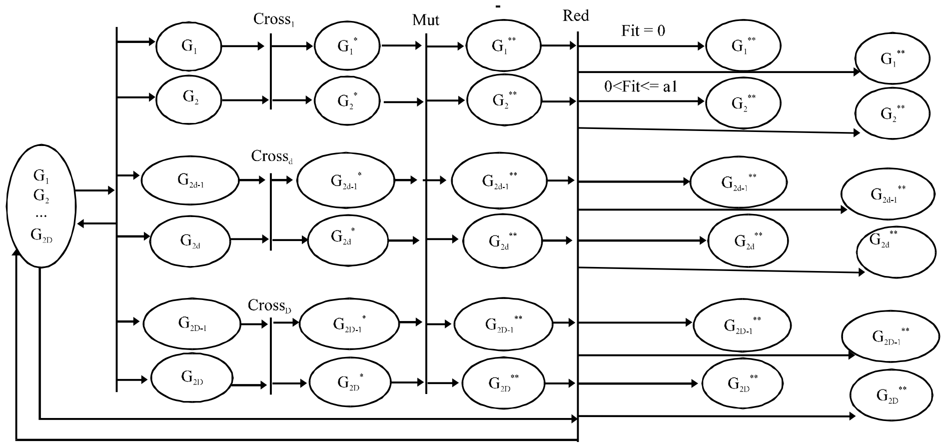

Fig. 2: Model of gentic algorithm baseed on nested petri nets

Proceeding from the presented model, it can be stated that the most time consuming in the calculation are the two operators of the genetic algorithm. Since, the size of the population and the size of the models can be very large, respectively, a computational experiment can be time-consuming.

To increase the speed of the present model of the genetic algorithm, it is proposed to use the approach based on parallel computations (Gladkov *et al*., 2006; Eiben *et al*., 1994). This approach makes it possible to use the properties of parallelism which is present both in the theory of petri nets and in genetic algorithms. The use of parallel computing should help to build the effective software and hardware implementation.

The calculations showing whether or not there is the possibility of increasing the speed of the proposed model of structurally-parametric synthesis of the discrete systems based on embedded petri nets using parallel computations and how this approach will be effective are presented herein. The Amdahl law which is the limitation of the growth in the performance of a computer system with an increase in the number of calculators is applied for this purpose:

$$S_p = \frac{1}{\alpha + \frac{1-\alpha}{p}}$$

Thus, in the presented version of the model, six operations are obtained, three operations of which must be performed sequentially and three operations that can be parallelized, i.e., N = 6, NPOSL = 3, NRASP = 3. In this case, α = NPOSL/N = 3/6 =0.5.

The calculations carried out, the possibilities of increasing the speed of operation of the GA on the VSP using the parallel computations are shown in Table 1. In accordance with the above calculations, it can be concluded that the application of the parallel computations in the implementation of the model of a genetic algorithm based on the embedded petri nets for solving the problem of structurally-parametric synthesis of the discrete systems is relevant and can yield the significant results with increasing the speed of software or h ardware implementation. The adaptation of the genetic algorithm to the domain of structural-parametric synthesis as well as a model description using petri net theory was carried out.

Table 1: The possibilities of increasing the speed of operation of the GA on the VSP using the parallel computations

P	1	10	20	30	40	50	60	70	80	90	100
Sp	1	1.818	1.904	1.935	1.951	1.960	1.967	1.971	1.975	1.978	1.980

The operation of the presented model is as follows: to choose a combination of models on the basis of which the structural and parametric synthesis will occur to perform the settings of the genetic algorithm operators to form the initial population (binary code lines) to specify the behavior of the synthesized LDSSB to set the stop condition to place the initial population in the starting position to start the proposed model at the end of the model, the output positions will be sorted by the value of the objective function of the chromosome.

The use of various parameters of the proposed procedure can lead to various solutions to the synthesis problem which can be combined into a selection set, after which the final decision is made by the decision-maker on the basis of their own (often not formalized) preferences.

CONCLUSION

The main result of this research is the formalization and algorithmization of the process of structural-parametric synthesis of large discrete systems with a specified behavior by forming a solution based on the specified components and the parameters of their operation.

In the research, a model was proposed that consists of four genetic algorithms, each of which performs the synthesis of the LDSSB based on its settings for working with the binary string. This approach makes it possible to carry out the synthesis both for one of the selected genetic algorithms and for their combination as well as the expediency of using the parallel computations for the software or hardware implementation of the GA.

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