Graphical Method for the Knowledge Base Analysis of the Simulation Model*

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Abstract. This article presents a method of analysis of the simulation models which are peculiar due to their graphical structure and declarative knowledge bases containing the description of the state of the modeled object and rules of its functioning. The models consist of intellectual agents, each of those having interfaces of external influence perception and being able to influence other agents through the transmission of control commands via the specified switching links. We have formalized the model and criteria of the analysis, defining operations for the model elements in the form convenient for the software implementation. We suggest the data base structure, providing a combination of graphical methods. Software tools have been completed in the form of a web application of an infographics library. Using this method allows us to analyze the structural links of the model, calculate functional load, and reveal errors in the knowledge bases and elements with lacking or excessive parameters and rules. The results of the method operation are interactive graphical presentations and automatically generated tables of errors and recommendations.

Keywords: Simulation Modeling, Spacecraft Onboard Equipment, Knowledge Base, Infographics, Agent Modeling.

1 Introduction

Modern scientific research has promoted agent-based simulation modeling which is a presentation of a model in the form of a set of agents and environment of functioning for the study of the behavior and interaction of complex objects. The science presents subject-focused tools designed for solving industrial and R&D tasks. For this purpose, they are supplemented with abstract elements, language constructions and sets of concepts taken directly from the subject area of research [1]. Agent-based modeling does not have a solid set of standard methods of the model development.

Widely used are intellectual simulation agents with the system of sensors for external influence perception. They interpret the received data on the basis of the embedded knowledge bases and reflect the events affecting the environment with the help of effectors [2]. Within the tasks of technical system production support, knowledge bases provide the accumulation and replication of the experience of highly qualified specialists in the subject area [3]. Such an approach is non-deterministic and allows one to define model functions as a result of the activity its agents. For graphical construction of the models in different systems the UML language is used, or a special set of graphical primitives allowing a high level of abstraction and independence from the method of the model implementation [4]. However, these models have a complicated graphical architecture and a declarative format of the simulation method presentation which requires the creation of special tools of the model analysis [5].

Model evaluation methods are mostly about getting information on how well the model describes real processes happening in the initial object, and how well it will simulate the development of these processes. Monitoring is performed on the basis of the statistical estimation of the simulation errors, however if there is no data of the functional testing of the object, this approach is impossible. In this case, specialists apply methods that use the qualified experience of experts in the subject area as well as empirical data and knowledge of the related areas [6]. They verify the consistency of knowledge on the basis of graph incidence matrices generalizing relations between the targets of the knowledge bases, analysis of knowledge reference integrity and search of the cycle dependences [7], etc.

The purpose of our study is to create a graphical method allowing one to analyze structural dependences in the knowledge bases of the simulation model in order to control their completeness, adequacy and consistency. The model elements are implemented in the form of intellectual agents simulating the logic of the onboard equipment operation. The models have been designed by specialists of the Institute of Computational Modeling within the software-and-hardware complex "Software-math model of the spacecraft command-and-measuring system of onboard equipment" [8]. This complex is currently a part of a space industry production process.

2 Graphical Method of Knowledge Base Analysis

2.1 Objectives of the Intellectual Simulation Model Design and Analysis

In order to create a method of intellectual simulation model analysis we have done the following: model formalization; data base creation; evaluation criteria definition; graph construction; error analysis; recommendation.

Model formalization implies the description of its elements and setting the criteria for analysis, which determine operations for the model elements in the form convenient for the software implementation. Intellectual simulation model is a set of intellectual agents describing the condition of the onboard systems and their functioning at each moment of time. The model elements are the following: B={B_i} – a set of intellectual agents, I= {I_q^i} – a set of switching interfaces, C={C^{ij}} – a set of links between the agents B_i and B_j. The connection is implemented by switching interfaces of the agents. Let us set C^{ij}_{nm}=<I^i_n, I^j_m>, where I^i_n is the interface of the agent B_i , I^j_m is the interface of the agent B_j. The agent contains a status block setting the values of the onboard equipment characteristics and a behavior block determining the strategy of its existence. The agent status is described by the following parameters: X – a set of incoming impacts, K – a set of control commands, Y – a set of output (monitored) parameters. The agent behavior is defined in a declarative form by the “condition-action” rules in the knowledge base. The rule R: $A \rightarrow Z$, where $A = A_1 \&$ … $\& A_r$ is the logical condition, $Z = Z_1$, …, Z_m are the actions changing the model state.

For the model analysis, we have designed a data base allowing one to store the graphical model and rules of the agents functioning in universal structures. The data base contains the following tables: ElementsOfModel – description of the model elements; Timer – timers; Interface – switching interfaces; Variable – model variables; Connection – links between the interfaces; Rule – knowledge base rules; LogicItem – a list of all the functioning devices with the description of actions; Timer_To_LogicItem, InterfaceToLogicItem, Variable_LogicItem – link tables of timers, interfaces and variables with the rules. The model contains 1500 thousand of items describing 13 blocks, 77 switching interfaces, 50 connections, 549 logical elements in 145 rules of the knowledge base. The complexity of the algorithm of pre-processing and analysis can be estimated by the expression $(b^2 l + 5b + 3i + 4c + 3r + rl + 2t)$, where b is the number of blocks, l is number of conditions/actions in the rules, i is the number of interfaces, c is the number of connections, r is the number of rules, and t is the number of timers.

On the basis of our formalization, and taking into account the given structure of the data base, we suggest the criteria for analyzing the functional dependences and control of compliance of the graphical structure of the model with the model operation methods determined by the knowledge base rules.

2.2 Method of Structural Link Analysis

This method allows one to estimate the correctness of using the graphical model elements in the knowledge base and to reveal structural errors. The criteria of structural link evaluation are as follows:

5. For switching interface the only allowed connection is: $\forall I^i_n \exists! I^j_m \mid C^{ij}_{nm} = \langle I^i_n, I^j_m \rangle \in C$.
6. Commutation connection is acceptable only through one-type interfaces: $C^{ij}_{nm} = \langle I^i_n, I^j_m \rangle\ Tp(I^i_n) = Tp(I^j_m)$, where Tp returns the type of the simulated interface.
7. Commutation connection is performed for multidirectional interfaces: $\forall\ C^{ij}_{nm} = \langle I^i_n, I^j_m \rangle\ Rt(I^i_n) \neq Rt(I^j_m)$, where Rt returns the direction by which the data of the simulated interface is transmitted, and takes the values of «Вх» (incoming) and «Исх» (outcoming).
8. For the incoming interface, there must be a rule set for the data reception: $\forall\ I^i_n \in I$ $Rt(I^i_n)$=«Bx» $\Rightarrow Sel(A^i, I = I_i) \neq \varnothing$, where Sel is the function of selection from the set of the elements with the given properties.

9. For the outcoming interface there must be a rule set for the data transmission: $\forall\ I^i_n \in I\ Rt(I^i_n)=«Исх» \Rightarrow Sel(Z^i,\ I=I_i) \neq \varnothing$.
10. For the interaction of the model elements specified by the rules, commutation connections must be determined: $\exists\ L(I^i_n,\ I^{i+l}_m) \Rightarrow \exists C_L=\{C_{pq}=\langle I^p,\ I^q\rangle,\ p=i,\ \ldots,\ i+l-1,\ q=p+1\}$, where $L(I^i_n,\ I^{i+l}_m)$ is the path between the agents B_i , B_{i+1}, …, B_{i+l} via the links set in C_L.

The criteria of the analysis are presented in a circle diagram of the structural links. Fig.1 demonstrates a part of this diagram with the dependent interfaces.

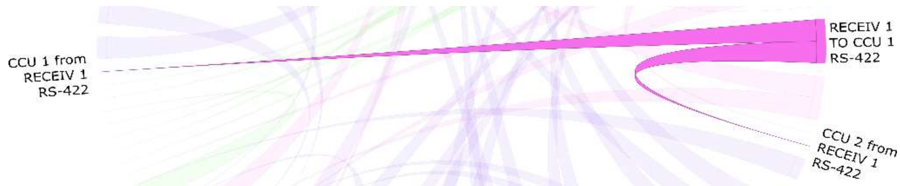

Fig. 1. Circle diagram of the dependences (extract).

The diagram sections are the model elements which are the simulators of the onboard devices, and the rays between them show the relations specified in the knowledge base. The Figure shows the commutation connections between the model elements: CCU 1, CCU 2 (simulations of the command-and-measuring system) and RECEIV (simulator of the receiving device). The ray width shows the direction of the data transmission.

Graphical visualization helps to reveal lacking or excessive structures, as well as model elements for which no rules have been specified in the knowledge base. This allows finding inconsistency between the graphical presentation and the knowledge base.

2.3 Method of Functional Load Analysis

Examination of the functional load is performed by the following criteria:

1. For all the elements of the model, the methods of functioning must be set: $\forall\ B_i\ \exists\ R_i \neq \varnothing$, where R_i denotes the rules of operation of B_i.
2. Equal functional load for one-type model elements must be provided: $\forall\ B_i \in B\ |R_i| \leq \frac{\sum_{j=1}^{|B|} |R_j|}{|B|} + \delta$, where $|B|$ is the capacity of the set, δ is the allowable functional load excess coefficient.
3. Equal functional load for one-type model interfaces must be provided: $\forall\ I_n \in I\ |Sel(R,\ I=I_n)| \leq \frac{\sum_{p=1}^{|I|} |Sel(R,\ I=I_p)|}{|I|} + \delta$.

The analysis is performed graphically. The nodes in the graph are the model elements, and the curves are the ways of their interaction with other sub-models (Fig. 2). The Figure shows the following model elements: CCU 1, CCU 2 (command-and-measuring system); OCS CU (onboard control complex); ODCC (onboard digital computing complex); ODGS, ODGS 2 (onboard remote signaling equipment), RECEIV 1, RECEIV 2 (receiving devices), TRANS 1, TRANS 2 (transmitting devices), RECEIV.AERIAL, TRANS.AERIAL (antennas); GCC (ground segment).

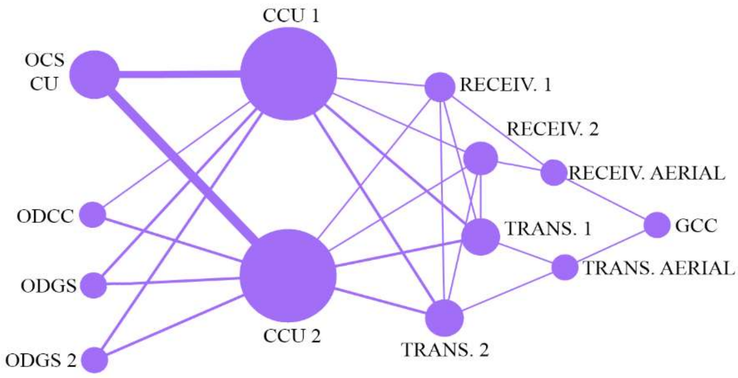

Fig. 2. Graph of the model functional load.

The size of the circles and curves demonstrates the amount of load calculated as the capacity of the set of rules, in which the model elements participate. High load for the model elements may become a reason for its revision or for the necessity of additional equipment and commutation.

2.4 Method of Complete Data Processing Analysis

The control of consistency is performed for the operation parameters and commands specified in the model description. There are the following criteria of the analysis:

4. There are rules for filling the model parameters: $Pr(R^i, X^i)\neq\varnothing$, where R^i is a set of the rules B^i, X^i are the input parameters of B^i, Pr is the projection function choosing all the elements from the set X^i, described in the rules.
5. There are rules of the model parameters interpretation: $Pr(R^i, Y^i)\neq\varnothing$, where Y^i are the output parameters of B^i.
6. For each command k there is a model element performing its transmission: $\forall\, k\in K$ $\exists\, B_i\, u\, \exists\, R_1\!: A_1\rightarrow Z_1,\, R_1\in Sel(R^i, K{=}\,k) \mid k\in Pr(Z_1, K)$.
7. For each command k there is a model element performing its reception: $\forall\, k\in K\, \exists\, B_j$ $u\, \exists\, R_2\!: A_2\rightarrow Z_2,\, R_2\in Sel(R^j, K{=}\,k) \mid k\in Pr(A_2, K)$.

The model implementation criteria are verified with the help of the coverage graph (Fig. 3), which demonstrates the model elements containing the nodes with no rules, or where no actions regarding the command reception or transmission have been specified for the interfaces.

The Figure shows the model elements listed in the load schedule and contains the details on switching links. This interactive graphical tool allows one to analyze in detail the implementation criteria with regard to the data for the model as a whole, as well as for each of the model, or switching interfaces.

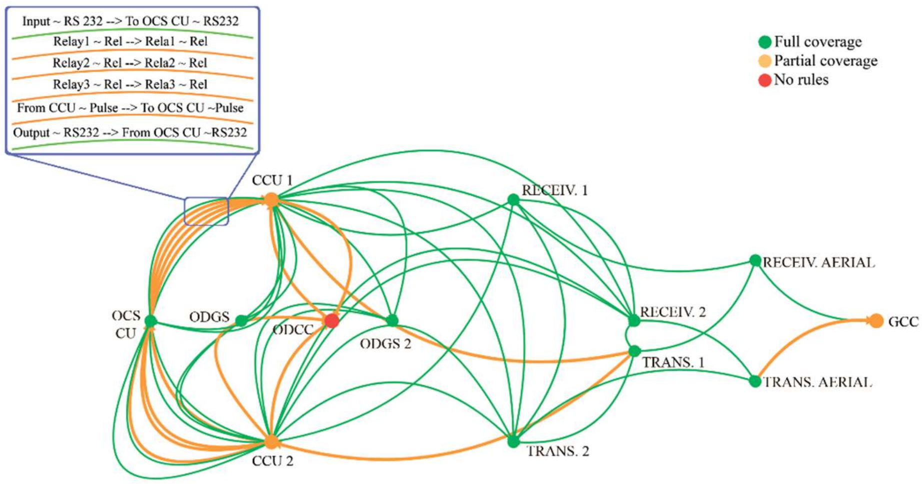

Fig. 3. Coverage graph with the interface details.

The following notation is used: green – the logic of reception/transmission is described for all switching interfaces of an element; red – all interfaces of an element have no description of the communication logic; orange – one or more interfaces in the element does not have any logic.

2.5 Method of Model Coherence Analysis

For the analysis of the functional dependences and in order to determine the model working modes specified in the knowledge bases of the intellectual agents we suggest the following criteria:

8. Each rule of the knowledge base must be included in one of the model functioning modes: $\forall\ R^i_j \in R^i\ \exists\ FMod \subseteq R \mid Sel(FMod, R=R^i_j) \neq \varnothing$, where *FMod* is a subset of the logical chains of the logical Inference.
9. Between the model elements with the dependent rule chains, commutation links must be set: $Dep(Rch^i, Rch^j) \Rightarrow \exists\ R_1: A_1 \rightarrow Z_1,\ R_2: A_2 \rightarrow Z_2,\ R_1 \in Rch^i,\ R_2 \in Rch^j,\ \exists\ C_{ij} = <I^i_1, I^j_2>,\ I^i_1 \in Pr(Z_1, I),\ I^j_2 \in Pr(A_2, I)$, where *Dep* defines the dependence relation of the rule chains Rch^i and Rch^j.
10. For all the interfaces, the rules of data reception or transmission must be set: $\forall\ I^i_n \in I\ Sel(R^i, I=I^i_n) \neq \varnothing$.
11. If there is a commutation link between the model elements, there exists a way of the data transmission via the interfaces included in this link: $\forall\ C^{ij}_{nm} = <I^i_n, I^j_m>\ \exists\ L(I^i_n, I^j_m)$.

Graphical interpretation of the specified criteria of the analysis is performed with the help of a coherence graph, describing the interaction of the model elements (Fig. 4). The graph shows the model elements for each switching interface, for example, «CCU1 to ODGS» – interface CCU1 (command-and-measuring system), which sends data to ODGS (onboard remote signaling equipment), «CCU1 from ODGS» – interface CCU1, which receives data from ODGS. The graph is divided into unrelated sections, for which the rules describe the events happening under certain conditions independently from other processes. If the knowledge base specifies multiple interactions between the model elements, the graph demonstrates all possible ways of data transmission, regardless of the conditions of the rule initiation. The graph gives specialist in the subject area a clear view of the simulation model operation modes set in the knowledge base.

In order to present the details the dependences realized during the logical output, rule chains are built, where each rule is a separate node initiated under the specified conditions. Such chains form precedents of simulation modeling and they are used for the model analysis [11] through the comparison with the results of the tests implemented on the simulated devices.

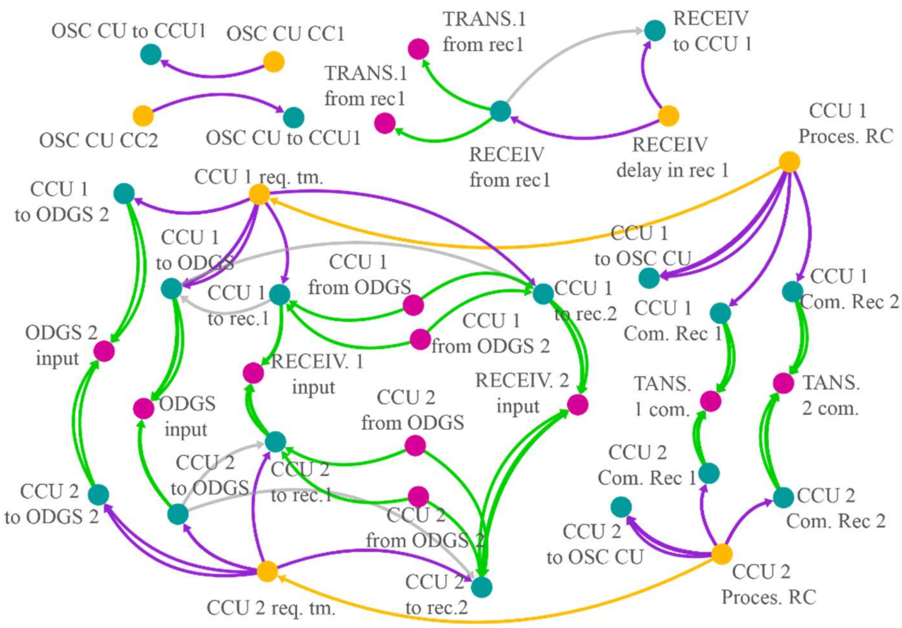

Fig. 4. Coherence graph.

3 The Application Results of Graphical Method of Analysis

The criteria of the analysis have been developed in the form of a web-application on the basis of the following software means and components: reception, pre-processing, analysis and interpretation of data for visualization, which are implemented on the server part of the application with the help of PHP7 scripts. At the core of the client's part, infographics libraries d3.js and sigma.js are used [9], providing interactive graphical tools for visualization of the functional dependences [10].

As a result of the analysis, tables of errors and recommendations are automatically generated. The table of recommendations contains data on the excess of the average level of the functional load for model elements (Fig 5).

Type	Name	Percent Exceeding Average	Guide
Device	CCU 1	381%	Recommended to reserve device
Interface	To Trans. 2 (CCU2)	50%	Recommended to reserve interface
Interface	Command (Trans. 1)	300%	Recommended to reserve interface
Connection	OSC CU - CCU 1	100%	Recommended to reserve connection

Fig. 5. Table of recommendations (extract).

The table of errors contains a list of the model elements and interfaces with the description of the errors found in the model structure or in the knowledge base. The table of recommendations provides a list of the elements, switching interfaces and connections for which the load is above the average calculated for all the model elements. It also gives recommendations on additional devices or communication lines. The model revision including the correction of errors and consideration of recommendations increases the quality of simulation tests, forming the base for the efficient task solution in the subject area.

4 Conclusion

The creation of an intellectual model is an important scientific task for the efficient support of the design of complex technical systems. However, in order to effectively use models and conduct simulation tests it is necessary to provide high quality and adequacy of the constructed models. Our graphical method of the simulation model analysis is designed to solve this problem. The method allows one to reveal the dependences of the model elements, errors of the knowledge base, lacking or excessive data and structures, for which no rules have been specified.

High representativeness is an advantage of our method. It provides a specialist in the subject area not only with automatic functions of the model control, but also with the tools of infographics allowing the examination of the simulated devices and checking of the compliance of the models with the technical tasks and design documentation. Implementation of the web technology provides simultaneous work of independent expert groups of different specialization. Owing to clarity, the acquired graphs can be used for the transfer of unique knowledge and for education of specialists via detailed immersion into the subject area.

The future development of the graphical method implies the study of structures of the model storage and its adaptation for other implementations. The distribution of analytical tools to the related subject areas demands the creation of additional tools of transformation of the existing formats of model storage into universal structures of the developed data base being an intermediate representation between model and software.

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