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Synthesis and analysis of hierarchical models of complex systems

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The majority of real-life systems are classified as complex ones, and, as a rule, they inhabit some specific characteristics which require holistic approaches for their study [1]. Typically, a hierarchical structure is used to reduce the complexity and make systems more manageable [2]. So the problem of synthesis of hierarchical models of complex systems and automation of the process of modeling and analysis attract much attention.

We propose an approach to the synthesis of dynamic models of complex systems which is based on the use of so-called *master-systems* consisting of canonical templates and expert knowledge-bases. The knowledge-bases consisting of declarative and procedural knowledge realize a conceptual model of complex system. The declarative knowledge contains: objectives tree of complex system that provides a decomposition of global goal on sub-goals and description of relation between them; the architecture and/or structure of complex system; the set of canonical templates; the set of models of canonical templates; problem domain databases.

The information about objectives tree is represented as the tuple $\boldsymbol{O}=(\boldsymbol{I}, \boldsymbol{Id}, \boldsymbol{G}, \boldsymbol{R})$, where $\boldsymbol{I}$ is a structure that determines the decomposition of global goal, $\boldsymbol{Id}$ is the structural identifier for nodes, $\boldsymbol{G}$ is a goal assigned to the node, $\boldsymbol{R}$ is a rule/law that describes the connection between the neighbor nodes. The canonical template is realized with the use of the language of *state transition diagrams* [2,3]. The canonical template has a certain structure: a set of input, output, and initial values/conditions. Formally the canonical template is described as $\boldsymbol{C}=(\boldsymbol{Str}, \boldsymbol{T}, \boldsymbol{X}, \boldsymbol{Y}, \boldsymbol{U}, \boldsymbol{Iv}, \boldsymbol{Tr})$, where $\boldsymbol{Str}$ is a structure of template, $\boldsymbol{T}$ is a rule/law of template functioning/behavior, $\boldsymbol{X}$ is a set of input parameters, $\boldsymbol{Y}$ is a set of output parameters, $\boldsymbol{U}$ is a set of control symbols, $\boldsymbol{Iv}$ is a set if initial values/conditions, $\boldsymbol{Tr}$ is a set of rules that govern the transformation of template structure, which means adding, modifying, removing links and/or nodes. Each canonical template model is assigned to one of the goals of the objectives tree.

The synthesis of dynamic models of complex system is realized by transformation of declarative knowledge about problem domain to the algorithms of system state dynamics by means of procedural knowledge.

The procedural knowledge is realized in knowledge-bases in the form of inference rules, which formalize the process of dynamic models synthesis. The inference rules provide the mapping of structure of conceptual model to the structure of dynamic models. The knowledge-base contains different groups of inference procedures depending on the purposes of investigation. For example, correspondence rules that determine for each canonical model the goal problems it solves; the inference rules that define informational relations between the templates in canonical model, etc. The representation of conceptual model of complex system in the form of knowledge-bases provides the autonomous usage of expert knowledge upon the synthesis of dynamic models. The above model is extended by adding to the canonical templates a set of control symbols, thus providing the dynamic models with the mechanism of system control. The dynamic (knowledge-based) expert system constructed in the form of master-system dynamically adjusts to the specific problem domain, provides corresponding templates for synthesis of models, connects with the appropriate database, and provides the relevant to the selected problems knowledge-base or its fragment.

The process of modeling and analysis of the complex system is based on the *hierarchical state diagrams technique* [4] that provides both qualitative and quantitative analysis of system behavior and state dynamics through the *hierarchical control scenarios* [4,5]. The method is especially powerful in information-intensive environments and can be successfully used for various kinds of systems such as technical, engineering, organizational, socio-economic, strategic planning, and decision support systems.

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