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DEVELOPMENT OF A SYNERGETIC RESEARCH ENVIRONMENT FOR MODELING COMPLEX PRODUCTIVE AND ECONOMIC SYSTEMS

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The paper deals with the problems associated with the development of modern computer technology decision-making in the digital economy, as well as methods, algorithms and software for solving control problems and decision-making in socio-economic production systems. The authors of the article propose a promising approach, having an interdisciplinary character, located on the border of the following areas: hybrid intelligent systems, synergistic artificial intelligence, neuro and psychophysiology, philosophy, cybernetics, economic and mathematical modeling, etc. Three laws of synergistic hybrid computational intelligence of complex, poorly formalized, multicomponent production and economic systems (SMPES) are considered: mutual adaptation, discrete series of structures and the law of transformations. A two-level model of the synergistic hybrid computational intelligence of the SMPES is presented, on the basis of which the evolutionary model of the synergistic hybrid computational intelligence of the SMPES is formulated. A model of the synergistic research environment of the SMPES based on hybrid computational models is considered. The architecture of the applied instrumental environment of "soft" mathematical modeling of SMPES is presented. The basics of creating a 5d technology platform for designing intelligent high-tech systems, enterprises and industries are presented, the main advantage of which is the use of a universal information platform in the form of a hybrid intelligent decision-making support system that quickly transforms into a specific system, specific subject area (mechanical engineering, heavy metallurgy, oil and gas, etc.), allowing you to add new quality to decision-making processes, as well as to ensure the creation and wide effective use of new knowledge, both for individual enterprises and entire industries, innovation clusters and zones. Based on the instrumental environment of "soft" mathematical modeling of SMPES and 5d technology-platform design of intelligent high-tech systems, enterprises and industries, the authors developed, patented and successfully implemented a set of applied tools for the development of key socio-economic sectors of the regions of the Russian Federation. The proposed methods, models and applied tools allowed the team to begin creating a universal, unparalleled in the world technology for the synthesis of innovative developments, products and high-tech services, obtained through the integration of various methods and applied tools and the subsequent generation of specialized technological chains and production and economic new generation systems.

Keywords: hybrid computing intelligence, production and economic systems, digital economy, innovative developments, mathematical modeling, synergistic model

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РАЗРАБОТКА СИНЕРГЕТИЧЕСКОЙ ИССЛЕДОВАТЕЛЬСКОЙ СРЕДЫ ДЛЯ МОДЕЛИРОВАНИЯ СЛОЖНЫХ ПРОИЗВОДСТВЕННО-ЭКОНОМИЧЕСКИХ СИСТЕМ

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Рассматриваются проблемы, связанные с развитием современных компьютерных технологий принятия решений в цифровой экономике, а также методы, алгоритмы и программное обеспечение для решения задач управления и принятия решений в социально-экономических производственных системах. Предложен перспективный подход, имеющий междисциплинарный характер, находящийся на границе следующих направлений: гибридных интеллектуальных систем, синергетического искусственного интеллекта, нейро и психофизиологии, философии, кибернетики, экономико-математического моделирования. Рассмотрены три закона синергетического гибридного вычислительного интеллекта сложных, слабо формализуемых, многокомпонентных производственно-экономических систем (СМПЭС): взаимной адаптации, дискретных рядов структур и закон трансформаций. Представлена двухуровневая модель синергетического гибридного вычислительного интеллекта СМПЭС, на основе которой сформулирована эволюционная модель синергетического гибридного вычислительного интеллекта СМПЭС. Рассмотрена модель синергетической исследовательской среды СМПЭС на основе гибридных вычислительных моделей. Представлена архитектура прикладной инструментальной среды «мягкого» математического моделирования СМПЭС. Представлены основы создания 5d технологии-платформы проектирования интеллектуальных высокотехнологичных систем, предприятий и производств, основным преимуществом которой является использование универсальной информационной платформы в виде гибридной интеллектуальной системы поддержки принятия решений, которая быстро трансформируется под системный характер, сложность, неоднородность конкретной СМПЭС, определенной предметной области (машиностроение, тяжелая металлургия, нефтегазовая сфера), позволяя придать новое качество процессам принятия решений, а также обеспечить создание и широкое эффективное использование новых знаний как для отдельных предприятий, так и для целых отраслей, инновационных кластеров и зон. На основе инструментальной среды «мягкого» математического моделирования СМПЭС и 5d технологии-платформы проектирования интеллектуальных высокотехнологичных систем, предприятий и производств разработан, запатентован и успешно внедряется комплекс прикладных инструментариев для развития ключевых социально-экономических секторов регионов РФ. Предлагаемые методы, модели и прикладные инструментарии, позволили приступить к созданию универсальной, не имеющей аналогов в мире технологии синтеза инновационных разработок, продукции и наукоемких услуг, получаемых на основе комплексирования различных методов и прикладных инструментариев и последующей генерации специализированных технологических цепочек и производственно-экономических систем нового поколения.

Ключевые слова: гибридный вычислительный интеллект, производственно-экономические системы, цифровая экономика, инновационные разработки, математическое моделирование, синергетическая модель

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Introduction. In the works of famous Russian scientists in the field of economic and mathematical modeling Prof. V.L. Makarova and Prof. G.B. Kleinar [1–7] the original approach to modeling hierarchical production and organizational economic systems based on various mathematical schemes (apparatus of abstract algebra, differential calculus, etc.) was summarized and comprehensively considered. The obtained models, on the basis of which the state space of a real system is modeled using the mathematical apparatus of the theory of lattices and other approaches, complement the models with an unstructured (automaton) and linear (linear systems) state space, etc. In fact, this class of models represents synergistic, hybrid formal schemes [8,9], designed to search for the universal principles of the formation and evolution of complex, industrial and economic systems [5–7]. Based on these works, as well as on works of other scientists, in various subject areas: mechanical engineering [10], oil and gas industry [11], agro-ecosystems and water ecosystems [8], socio-economic sphere [12], etc., – the authors of the article formulated a statement regarding the need to revise, supplement the traditional approaches to the construction of mathematical models of complex, including poorly formalized, productive and economic systems [13], and also set the task of creating new directions, approaches and methods in the field of mathematical modeling and synthesis of complex systems capable of providing at a qualitatively different level the possibility of formal models development of complex productive and economic systems. In fact, it was about creating new classes of mathematical models of complex productive and economic systems, with an adaptive, synergetic structure [14, 15] – as a special class of «soft» mathematical models based on the principles of adaptive heuristic adjustment [8, 9] of analytical dependencies with heuristic knowledge and soft calculations.

Despite the importance of this task, the research works in this area did not gain active development. In 2016 at the international conference "Hybrid and Synergetic Intellectual Systems: Theory and Practice (GISIS-2016)" (Russia, Kaliningrad, the conference was held with the support of the Russian Foundation for Basic Research) the authors first proposed and received a widespread approbation of a concept of «soft» mathematical modeling of complex systems, based on hybrid computing intelligence [9] as a new interdisciplinary research area located on the «boundary» of: hybrid intelligent systems, synergetic artificial intelligence, mathematical modeling of complex systems, systems theory and systems analysis.

In the study [15] the concept of complex, multi-component productive and economic systems, functioning in conditions of uncertainty, and poorly formalized problems was introduced [14]. The set-theoretic representation of the specified class of complex systems is also implemented in the sources [8, 9].

In the studies [9, 13, 15] a statement regarding the need to revise, supplement, traditional approaches to the construction of mathematical models of complex, including poorly formalized, productive and economic systems (PES) was formulated, and also the task for creating new directions, approaches, methods and applied tools in the field of modeling of complex, multi-component production and economic systems (CMPES) was set.

Purpose of the study. Accumulated to date, in the framework of this approach (the concept of «Soft mathematical modeling of complex systems based on hybrid computing intelligence [9]»), extensive theoretical and practical experience [8,9,15] in various subject areas (agriculture, oil and gas sector, engineering, military-industrial sector, etc.), allowed the authors to formulate the basic theoretical positions in the field of creation of a synergetic research environment for modeling complex, productive and economic systems and also to set the task for developing on its basis a complex of applied systems of various types and purposes.

Research methodology. In the work [9] three laws of synergetic hybrid computing intelligence (HCI): mutual adaptability, discrete structures, and the law of transformations – were formulated.

Due to the fact that the structure of synergetic HCI is a reflection of certain regularities of mutual adaptation of internal components, the law of mutual adaptability determines the presence of internal mutual adaptability processes between components of synergetic HCI as a necessary and sufficient condition for the emergence and development of synergetic HCI.

In accordance with the law of discrete structures, the new structure of synergetic HCI is synthesized from a discrete series of its possible structures. Thus, a method can be obtained for synthesizing the target structure of the synergetic HCI, included in a discrete series, from another structure of this series.

In accordance with the law of transformation, the transformation of one structure of synergetic HCI into another by means of knowledge common to both structures can be achieved. Thus, the law of transformations implies the possibility of creating a method of forming new knowledge, obtaining their interference, as well as the transition from one knowledge to new knowledge, interrelated, associated with the previous one.

In accordance with the law of transformations – the synthesis of a new structure of synergetic HCI is possible only on the basis of the previous structure, which leads to the mutual adaptation of some of the components corresponding to the new structure. Within the framework of the concept of «soft» mathematical modeling of the complex, multi-component productive and economic systems, the law of transformation determines the primary role of fundamental, formalized knowledge in the new structure of the synergetic HCI, as well as the possibility of their integration in the development process with newly emerging heuristic knowledge.

In view of this, the concept of synergetic hybrid computing intelligence is illustrated in Fig. 1. Fig. 1 shows a two-level model of synergetic hybrid computing intelligence [9]: at the macro level – the method as a whole; at the micro level – decomposition of the method using the triad «language – model – procedure».

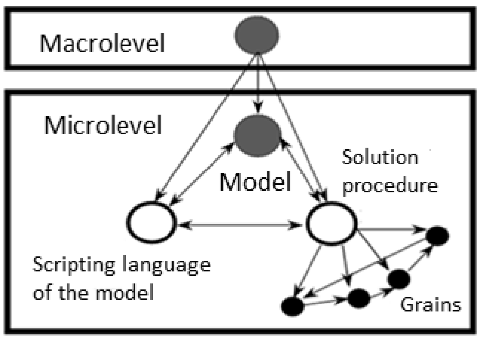

Fig. 1. Two-level model of synergetic hybrid computing intelligence

The modeling method and the corresponding CMPES formal model are two closely interconnected objects. Since the formal model of CMPES has been developed in accordance with a certain modeling method, it is connected with its properties, and obtains all the pros and cons of the method; the same applies to the modeling method that inherits the model properties. Moreover, the modeling method cannot go beyond its model and acquires from it the structuring of the external world, the conceptual apparatus, which largely determines the strength and capabilities of the method. In the study [9] the concept of «phenotype $\leftrightarrow$ genotype» of a modeling method is considered, as well as the laws of transformation of modeling methods when solving applied system problems [9] in complex, multi-component productive and economic systems.

This approach to the representation of the modeling method allowed us to formulate an evolutionary model of synergetic hybrid computing intelligence (Fig. 2) [9].

The evolutionary model of synergetic hybrid computing intelligence leads to the possibility of creating integrated methods – method-systems [9], built using integration relations on a variety of genotypes of other types, and synthesis of integrated models of CMPES – systems of models [9]; built with the help of integration relationships on a variety of other models. Thus, the desired macro-level properties (the goal of hybridization) of descendant methods can be obtained: $Method_1^{\Pi}$, ..., $Method_{N_{\Pi}}^{\Pi}$, representing synergetic hybrid systems [9], and corresponding properties of integrated models of CMPES.

An evolutionary model of synergistic hybrid computational intelligence allows us to formulate a model of a synergistic research environment based on hybrid computational models derived from synergetic hybrid systems.

Suppose Iv^m – set of applied systems [9]. We introduce a set of hybrid computational model, $LANG^m = \{LANG_1^m, \ldots, LANG_{N_{LANG_m}}^m\}$ and set the correspondence $\Psi^{LANG,Iv}: LANG^m \to Iv^n$.

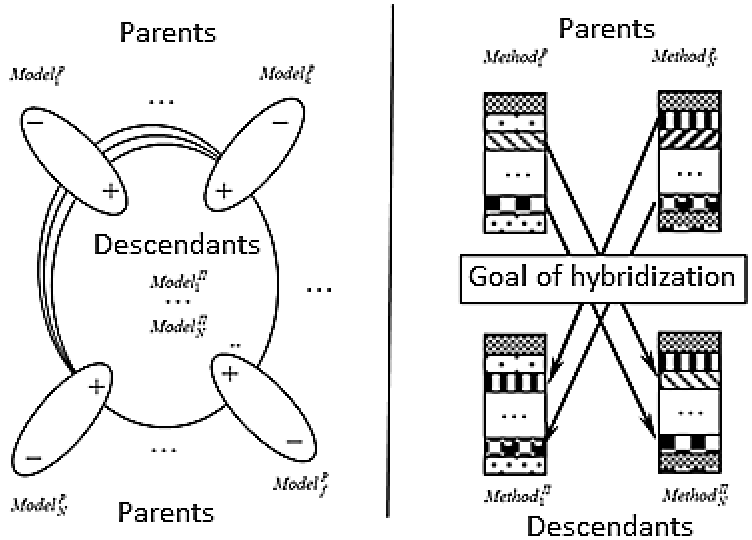

Fig. 2. Evolutionary model of synergetic hybrid computing intelligence

We introduce five sets of micro-level representations of autonomous methods [8, 9]:

$$MET^a = \{MET^a_{An}, MET^a_{St}, MET^a_{Lg}, MET^a_{Li}, MET^a_{Ep}\},$$
$$MET^a_{An} = \{met^a_{An1}, \ldots, met^a_{AnN_{An}}\},$$
$$MET^a_{St} = \{met^a_{St1}, \ldots, met^a_{StN_{St}}\},$$
$$MET^a_{Lg} = \{met^a_{Lg1}, \ldots, met^a_{LgN_{Lg}}\},$$
$$MET^a_{Li} = \{met^a_{Li1}, \ldots, met^a_{LiN_{Li}}\},$$
$$MET^a_{Ep} = \left\{met^a_{Ep1}, \ldots, met^a_{EpN_{Ep}}\right\},$$

works with An-, St-, Lg-, Li-knowledge и Ep-experience, where N_{An}, N_{St}, N_{Lg}, N_{Li}, N_{Ep} are the number of known m^a-methods.

We define five sets of one-to-one correspondence $\Psi_i^{met\ met}$, when $i \in \overline{1,5}$ and met^a_{dl}, $j = l$; $d, q \in \{An, St, Lg, Li, Ep\}$; $d = p$:

$$\Psi_1^{met\ met} : MET^a_{An} \to MET^a_{An},$$
$$\Psi_2^{met\ met} : MET^a_{St} \to MET^a_{St},$$
$$\Psi_3^{met\ met} : MET^a_{Lg} \to MET^a_{Lg},$$
$$\Psi_4^{met\ met} : MET^a_{Li} \to MET^a_{Li},$$
$$\Psi_5^{met\ met} : MET^a_{Ep} \to MET^a_{Ep}.$$

We define correspondences $\Psi_i^{MET\ LANG} : \Psi_i^{met\ met} \to$ $\to LANG^m$ and get five sets, elements of which are tuples $((met^a_{dj}, met^a_{ql}), LANG^m_w)$, where $w \in \overline{1, N_{LANG}}$.

Thus, we have the following model of a synergetic research environment, the elements of which are presented in detail in [8, 9]:

$$E^M = \left\langle LANG^m, MET^a, \Psi_i^{met\ met}, \Psi^{MET\ LANG} \right\rangle. \quad (1)$$

Approbation and results. Based on (1), the applied instrumental environment of the «soft» mathematical modeling of complex, multi-component productive and economic systems [9] was developed (Fig. 3).

The developed model of the synergetic research environment and the instrumental environment of «soft» mathematical modeling of CMPES created on its basis made it possible to set the 5d technology-platform for designing intelligent high-tech systems, enterprises and industries [9] (Fig. 4).

Studies [8,9] showed that the proposed 5d technology-platform for designing intelligent high-tech systems, enterprises and industries [9, 15] can quickly adapt to a system-based nature, complexity, heterogeneity of applied CMPES, various types and purposes, allowing to bring the decision-making process in applied CMPES to a whole new level [13], to ensure the synthesis, as well as a comprehensive and effective use of new knowledge [20, 21], both for individual enterprises and entire industries, innovation clusters and zones.

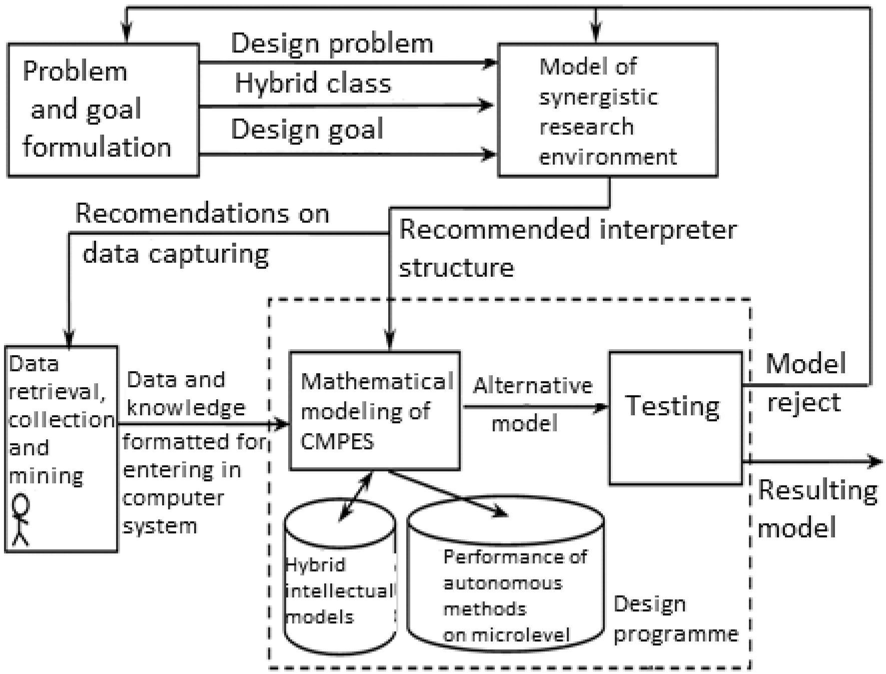

Fig. 3. Instrumental environment of the «soft» mathematical modeling of CMPES

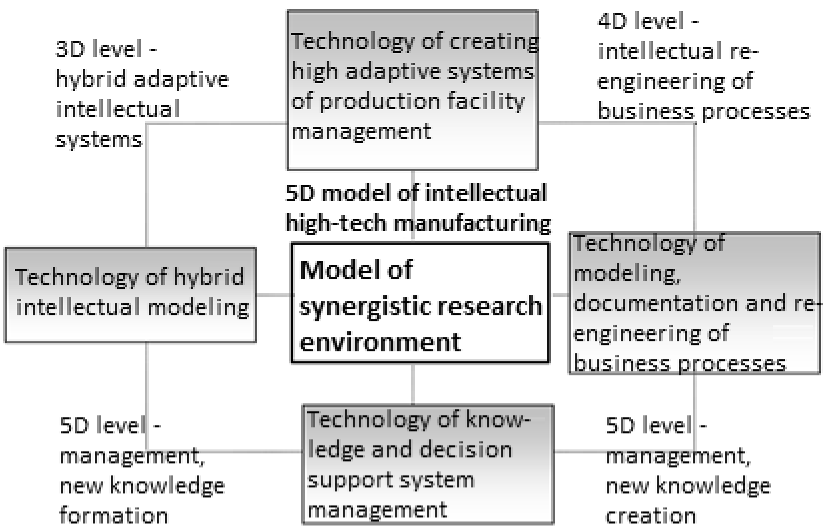

Fig. 4. Technology-platform for designing intelligent high-tech systems, enterprises and industries

Based on the instrumental environment of "soft" mathematical modeling of the CMPES and 5d technology-platform for designing the intelligent high-tech systems, enterprises and industries, the authors developed, patented a set of applied tools [22, 23] for the development of key socio-economic sectors in the regions of the Russian Federation, which is being successfully implemented.

Results

1. Three laws of synergetic hybrid computational intelligence of complex, poorly formalized, multi-component productive and economic systems are considered.

2. A two-level model of synergetic hybrid computational intelligence of complex, multi-component production and economic systems is

presented, on the basis of which an evolutionary model of the synergetic hybrid computational intelligence of CMPES was formulated.

3. A model of the synergetic research environment of the CMPES based on hybrid computational models is considered.

4. The architecture of the instrumental environment of «soft» mathematical modeling of CMPES is presented.

5. The main elements of 5d technology-platform for designing the intelligent high-tech enterprises and industries are considered.

Conclusion. In the course of solving the tasks of advanced (breakthrough) innovative development of the Kaliningrad region, creating a scientific, technical and technological base on the ground of advanced world achievements and breakthrough technologies, the collaborative writing team in 2014 formulated the idea and the main positions in the field of creating the first Russian Center of Computer Engineering and systems engineering design of high-tech systems and productions. In the period from 2014 to the present, the writing team carried out a huge organizational, research and development work, which resulted in the creation of an intellectual and technological basis for the unique, one-of-a-kind in Russia, innovation and technology center «Baltic Engineering Center of hi-tech systems and productions» (supervisor: Prof. Sergei Korjagin, Baltic Federal University of Immanuel Kant), including: a complex of modern educational, scientific and innovative laboratories; developed an advanced scientific-methodological platform «Intellectual Systems Engineering [8]», which represents an interdisciplinary scientific-methodological basis that provides the generation of new knowledge in the inter-, multi- and trans disciplinary areas to solve complex problems of industry, energy, transport, engineering, etc.; developed and patented a unique (ensuring the creation in the shortest possible time of competitive products of the new generation) application-oriented basis of high-tech solutions and tools. At present, on the basis of the methods, models and applied tools proposed in this scientific article, a set of advanced production solutions for the development of socially significant sectors of the regional economies of the Russian Federation has been successfully implemented [22, 23] based on the Baltic Engineering Center, as well as a set of federal-level projects that are important for solving national production, economic and other strategic tasks of the Russian Federation was launched.

Directions for further research. Accumulated to date, a large theoretical and practical experience of applying the model of a synergetic research environment in various subject areas (agriculture, oil and gas sector, engineering, military-industrial sector, etc.), allowed the authors to proceed to the development of the proprietary, internationally advanced, technology for synthesizing innovative developments, products and high-tech services, obtained through the integration of various methods and applied tools, and the subsequent generation of specialized technological chains of the new generation, which allows accumulating advanced science, basic and critical military and industrial technologies, ensuring the generation of new knowledge in cross-, multi- and trans disciplinary areas for solving complex problems of industry, energy, transport, engineering, and etc.

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