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Creation of intellectual decision-making systems in industry based on hybrid computing methods

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Abstract. This paper describes the promising approach in creating applied intellectual decision-making systems in industry (different types) of the new generation, based on authors synergetic collective decision-making model and methods of hybrid computational intelligence, which allows us to significantly increase the quality of the results of computer-aided solutions to complex applied problems in information variety and heterogeneity as well as to enhance decision-making by reducing losses from erroneous and individual solutions which are irrelevant to the problem complexity. There is an example of successful application of proposed methods in modeling significant class of complex application systems in medical industry, i.e. multicomponent, poorly formalized systems functioning in various types of uncertainty. The paper presents perspective approach in the field of creation of applied intellectual systems of decision-making of new generation, on the basis of author's synergetic model of collective decision-making and methods of hybrid computing intelligence. This approach allows to significantly increase quality of results of the automated solution of complex applied challenges in the conditions of a variety and heterogeneity of information, and also to increase efficiency of decision-making due to reduction of losses from wrong and irrelevant difficulties of a task of individual decisions that results of laboratory experiments confirm.

1. Introduction

According to Klachek [1], a hybrid intelligent system (HIS) is the system in which more than one simulation method of intellectual human activities is used for complex task solution. Despite major advances in the use of HIS especially in semistructured domains [2, 3] effective application systems for solving difficult to formalize tasks have not yet been created. The main problem is that in dealing with applied tasks in industry [4] based on HIS, integration of two or more functional components (modeling techniques) [5, 6] is required, causing serious problems (presented in detail by Klachek and Castillo [1, 2]) in the field of integration and management of formalized and weakly formalized knowledge [7], and in creating an application software that requires innovative approaches usage.

2. Purpose of the study

According to Klachek [1], three concepts – “a synergetic model of collective decision-making [5]”, “a decision support system [7, 8]” and “a hybrid computational intelligence” - are considered together.
The synergetic model [2, 3, 5] of collective decision-making simulates the multilingual character [1, 9] of solving complex applied problem-systems in industry [1, 4, 9, 10] on the one hand, and social collective nature of decisions [8], on the other hand.

Hybrid computational intelligence (HCI) [1, 5, 7] — is an instrument of synergetic artificial intelligence [2, 3] designed to simulate effects of interaction, self-organization and adaptation observed in systems where the nature [11], people and technology [12, 13] are closely intertwined.

Joint consideration of three mentioned complex concepts opens the way to a promising engineering technology (the basics of which are presented in this article) in the field of creating applied intellectual decision-making systems of the new generation capable to integrate diverse knowledge models (in the following – the heterogeneous model field [5, 7]), and thus solving the problem of improving quality of computer-aided solution results to complex applied problems in industry in the context of information variety as well as enhancing decision-making by reducing losses caused by individual solutions which are erroneous and irrelevant to the problem complexity.

3. Methods of research

According to the law of requisite variety [1, 14], only multivarious and coordinated analytical activity, whose elements in combination solve one problem, will make the result of decision-making qualitatively better. The specific nature of this work is consistent with the collective work of experts in small groups – the councils. Figure 1 shows the conceptual model of collective decision-making by a small experts group (SEG).

Figure 1. The conceptual model of collective decision-making.

Notation: $R_{LPR\_VS}$, $R_{LPR\_E}$, $R_{E\_E}$ – are the information relations “external environment - decision maker”, “expert - decision maker”, “expert – expert”, respectively; $S_{R_{LPR\_VS}}$ – is the cooperative relationship “decision maker – expert”.

Advantages of SEG are focused on the implementation of ideas that are not feasible for individual decision-making because the individual decision maker (DM) has no opportunity to go beyond his immediate activities. Synergetic effect in SEG is achieved by “the group compensation of individual disabilities [1]”. It is proposed to use SEG simulation and the resulting synergy together with HIMAS [15], which are hybrid intelligent systems (HIS), practicing multi-agent approach [15]. Elements of such HIS are realized in the form of agents having the property of autonomy [15]. Like multi-agent systems (MAS), they simulate interactions of autonomous agents with each other and with external environment, as a result of which, system architecture can be dynamically reconfigured in accordance
with specific functions (roles) of agents and relationships established between them. As a result, HIMAS combines positive aspects of HIS and MAS: because of the combination of several methods of artificial intelligence, they are relevant to problems with high simulation complexity [5]; due to simulation of interaction of experts and resulting collective processes, they can change their architecture so as to achieve synergistic effect. For computer realization of SEG model, HIMAS functional structure is developed (figure 2) [15].

Central element of HIMAS shown in figure 1 is a subsystem of “Hybrid computational intelligence (Decision-making agent, figure 1)”. The concept of the hybrid computational intelligence occurs when the decision maker in the Decision Support System (DSS) breaks up a single whole (see figure 1), i.e. the initial problem into its constituent parts, and entrusts the solution of subproblems to the experts.

**Figure 2.** Functional structure of hybrid intelligent multi-agent system (HIMAS [1]). 1 – Logical agent, 2 – Fuzzy agent, 3 – Converter agent, 4 – Linguistic agent, 5 – Subject domain model, 6 – Finding-solution agent 4, 7 – Finding-solution agent 3, 8 – Finding-solution agent 2, 9 – Finding-solution agent 1, 11 – Interface agent, 10 – Decision-making agent, 12 – Proxy agent, 13 – Analysis agent, 14 – Stochastic agent.

In figure 3 model of the problem has a two-level representation: at the macro level - the problem as a whole and its properties; at the micro level - a system of subproblems (light circles) and a coordinating problem (dark circle). A complex problem is a problem-system [5], which includes interrelated domains of var parameters [1]: determinated, stochastic, linguistic and genetic in which cause-effect relationships of expert arguments are specified by representations — analytical, statistical, expert, fuzzy, neural and genetic.
Figure 4 shows synergetic model of hybrid computational intelligence [5] which is the characteristic of collective decision-making model of SEG (figure 1).

Experts who are solving parts of the general problem-system (figure 3) create parent models (figure 4, a): \( Model_1^P, ..., Model_k^P, ..., Model_{N}^P \), while the variety of team work structures used in DSS (sequential, simultaneous, formation of subgroups, coalitions, etc.), i.e. the usage procedure of parent models for joint reasoning, determines the variety of descendant models: \( Model_1^D, ..., Model_{N}^D \). These models relate to the general problem-system. Descendant models are hybrids obtained on a heterogeneous model field [1] by means of functional feature-based combining and inheriting of positive aspects of the reasoning methods applied by experts to solve parts of the original problem. We call such hybridization, obtained within the synergetic model of hybrid computational intelligence, a coarse-grained one [1]. Figure 4, b shows another pattern: the expert’s sensation that none of the known prototype methods are suitable for solving the subproblem. This sensation arises when expert is not satisfied with certain aspects of the methods. For example, one of them leads to models with intolerable error, but with good computational capabilities, and the other gives opposite picture. The expert starts to consider the tool for solving the problem at different detail levels.

Figure 4. Synergetic model of hybrid computational intelligence.

In [1] the concept of “hybridization direction”, consisting of two levels: 1) “from the problem”; 2) “from the method” is introduced. The point of the direction “from the problem” is that the problem
should be considered at macro and microlevels. Macrolevel (problem phenotype) — defines the problem entirely as a complex entity, a system. The micro level (functional feature level) is a set of subproblems, related in decomposition by the relation classes. Macro- and microlevel representations of the problem are interrelated and should be considered in unity. Hybridization “from the problem” requires: 1) research and extraction of knowledge about the macrolevel and microlevel representations of the problem; 2) research and extraction of knowledge about the interdependencies of macro- and microlevel representations.

The point of the direction “from the method” is that each method of a limited set should be considered at macro- and microlevel. The macrolevel (method phenotype) is a method entirely as a complex entity, a system. Microlevel (method genotype) is a set of grains “model”, “description language”, “solution procedure” or grains of a more detailed level as components of the decision procedure. Macro- and microlevel representations of the problem are interrelated and should be considered in unity. Hybridization “from the method” requires: 1) research and extraction of knowledge about the possibilities of methods; 2) research and extraction of knowledge about macrolevel and microlevel representations of methods; 3) research and extraction of knowledge about the interdependencies of macro- and microlevel method representations.

4. Approbation
To approbate the proposed solutions, the diagnostics problem of arterial hypertension (AH) was chosen - one of the most widespread diseases of the cardiovascular system. It is established that 20-30% of the world’s adult population suffer from arterial hypertension (WHO data). To study the diagnostics problem of arterial hypertension (DPAH) the method of mixed reduction [16] was applied, based on the recommendations of the committee of experts of the Society of cardiology of Russian Federation (SCRF) and extraction of expert knowledge. Decomposition of DPAH including 12 diagnostics and 9 technological subproblems is constructed. Diagnostics subproblems grouped and indexed into nine areas of homogeneous parameters: target lesions, 11 risk factors of cerebrovascular diseases, metabolic syndrome and diabetes, diseases of the peripheral arteries, ischaemic heart disease, endocrine AH, parenchymal nephropathy and renovascular AH.

The method choice for computer-aided solution of diagnostics subproblems and analysis of instrumental heterogeneity of the hypertension diagnostics problems is made on three-quadrant matrix data model that contains “method—characteristics”, “problem—characteristics” and “problem—method” knowledge [5, 8], what allowed us to set and investigate correspondence on sets of diagnostics subproblems and basic methods. General, qualitative characteristics of methods were taken into account to ensure the required functionality of the system entirely. As a result, the developed heterogeneous model field consists of 14 functional models: two artificial neural networks, nine fuzzy systems, two expert systems and technological models: nine genetic algorithms.

Figure 5 shows an example of functional scheme of the HIMAS hybrid computational intelligence subsystem (figure 2) of arterial hypertension diagnostics, based on the model of artificial neural network of ECG recognition and the fuzzy system model of ischaemic heart disease diagnostics.
Figure 5. Functional scheme of HIMAS hybrid computational intelligence subsystem.

Notation: $X_{128d=1}^{\text{mod}_n}$ – a 128×1 matrix of input vector of the modular artificial neural network model of ECG recognition; $Y_{7d=1}^{\text{mod}_n} = (y_0, ..., y_6)^T$ – is a 7×1 matrix of output vector of the HIMAS-AH prototype; $f_1, f_2, f_3$ are synaptic weights matrices of the input, hidden and output layers; $DAG_6$ – is an interface for information exchange between models that solve the subproblem of ECG recognition and ischaemic heart disease diagnostics; $\text{TRANS}$ – is a conversion procedure; $\mu_{A}(x)$ – membership functions.

Laboratory experiments with the HIMAS-AH prototype (a hybrid intellectual multi-agent system for arterial hypertension diagnostics developed within the grant of the Russian Foundation for Basic Research (RFBR project No. 16-07-00272)) produced the following results:

1. With the use of HIMAS-AH, total time of examination and result processing is approximately 30 seconds, which is seven times less than diagnostics time when experienced doctors work together with a nurse;

2. A standard deviation in the diagnosis, based on the use of HIMAS-AH, was $\sigma = 0.0837$, i.e. HIMAS-AH gives a reliable diagnosis in 92% of cases. Thus, the use of HIMAS-AH on the basis of fine-grained hybridization (figure 4, b) gives better results than with a homogeneous approach, for
example, the well-known “Diagnosis” project [16] - a system with a knowledge base to support decision making on AH diagnostics using logical-linguistic methods with the R. Carnap confidence factors method, which only in 60% of cases formed a right detailed differential diagnosis.

5. Conclusion
The tradition of complex problem solving by expert teams led by the DM, has old roots: military councils, collegium of Ministry, all kinds of meetings, briefings, concilia, think tanks etc. [14, 17]. Relevance of team-based problem solution is stipulated by advantages over individual's work: improving of decision quality by considering the variety of opinions and integrating of various specialists knowledge; enhancing of confidence of all collective members in results of its work and motivation to implement such decisions; compliance with ethical standards. Experienced decision-makers provide conditions for the emergence of positive group effects and minimize negative ones, rearranging the control system composition and structure, adapting to changes in the external environment. The problem is that most part of modern computer technologies is the medium of methods implementation - not the tool for their synthesis. Hence, similar to computer expert systems [6, 10], arguing “no worse” than one person, the information technologies are not worse than the collective of specialists for management in the conditions of complex problems. The paper is addressing a promising approach in creating applied intellectual decision-making systems of the new generation based on author-proposed synergetic collective decision-making model and methods of hybrid computational intelligence enabling us to significantly increase quality of results of computer-aided solutions to complex applied problems in information variety and heterogeneity as well as to enhance decision-making by reducing losses caused by erroneous and irrelevant (to the problem complexity) individual solutions that is confirmed by the results of laboratory experiments performed with involvement of hybrid intellectual multi-agent system for arterial hypertension diagnostics developed within the grant of the Russian Foundation for Basic Research (RFBR project No. 16-07-00272). The work in this direction continues intensively.

6. Directions for further research
A separate task of HCI and HIMAS is a targeted study and modeling of complex, multicomponent application objects, phenomena and systems which function under various types of uncertainty [1, 5, 7]. Despite some serious achievements in this area [1, 2] in particular during modeling and management of bioproduction [5], water ecosystems [5] etc., based on HCI and HIMAS, results were insignificant so far in comparison with classic mathematical approaches [1, 5, 8, 18, 19]. Thus, there is a need for further research in the field of HCI and HIMAS related to modeling of important class of applied, complex systems in industry [4, 13], i.e. multicomponent [5, 10, 13], poorly formalized [5, 7] systems operating under different types of uncertainty [1, 9, 12, 20, 21].

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