Problem-Structure Technology for Hybrid Intelligent Systems Development

Alexander Kolesnikov
Control Systems & Computers Department, Kaliningrad State Technical University,
Kaliningrad, Russian Federation
kolesnikov@baltnet.ru

Abstract

Hybrid intelligent systems (HYIS) are the object of studies. They integrate the advantages of autonomous approaches for solving of complex practical problems. An original PS-technology for HYIS development is introduced. The technology offers the system analysis of the problem and synthesis of the structure that is relevant for the properties thereof. The technology was applied to the heterogeneous problem of strategic planning for the agricultural companies. The results of experiments with HYIS are considered.

Keywords: technology, development, hybrid intelligent system.

1. Introduction

In recent years the term of intellectual control is actively used in the systems theory [7,8,15]. This term emphasises heuristic (expert, adaptive, fuzzy, evolutionary and other) corrections of formal mathematical description of the object of control for modelling dynamics of the system. A group of the scientists headed by E.A.Feigenbaum from Stanford University undertook one of the first attempts of such correction in the 70 s. They were looking for ways of overcoming the drawbacks of GPS – the General Problems Solver in the world of mathematical brain-twisters with a comparatively small set of states and well-known formal rules. Instead of searching for efficient universal heuristics, they started contracting the problem area, studying informal knowledge and skills of a specialist and developing systems, based on knowledge of the 'condition–action' type. However very soon [5,6] the one-sided character of insufficiency of such an autonomous expert, natural language (symbolic) correction became obvious: it did not cover fuzzy reasoning of a specialist, it was crisp [24], it hardly coped with noise, it did not explain at all quick low-level reactions of a person to changes of environment. Therefore on the border the 70 s and 80 s the paradigm of refusal of abandoning the principle of absoluteness of a certain type of knowledge for developing intellectual of transition to mutual-correction, mutual-compensation of drawbacks and to cooperation of model ensembles appeared [9]. This paradigm confirms that there isn't a single, final method, which will explain or solve a complex practical problem. Instead of this the developer has a certain number of models and tools used under different circumstances [24]. The synergetic structure (from the Greek word sinergia - cooperation, assistance) can be built on the basis of the ensemble of such autonomous models. The structure uses and manages the advantages of different presentations simultaneously in other to overcome the imperfections of the other ones. The development of such structure is associated with designing a method of explanation or solving a difficult problem. The typical examples of such structures are hybrid systems [23], hybrid intelligent systems [24,25-29,32-34,37], multi-agent systems [21,35], and hybrid (integrated) expert systems [4,18].

Hybrid intelligent systems (HYIS) are objects with the synergetic effect, which integrate different types of knowledge with a view to mutual-compensation of disadvantages and pooling the advantages of heterogeneous models. This makes it possible to expect good prospects of HYIS for

---
1 Presented research partially supported by Russian Foundation for Basic Researchers and of the Committee for Scientific Studies of the Republic of Poland (grants 98-01-00081 and 8T11A00813).
complex practical (not toy) problems solving, which cannot be reduced to homogeneous presentations and corresponding algorithms of reasoning (searching) of decision on the bases of models of intellectual control.

2. Hybrids and hybridization

The origin of hybrids (from the Greek word 'hybris (hybridos)' - an organism, appearing as a result of hybridization [19]) can be of traced ancient legends about the origin of mankind or in more recent papers by geneticists, however in both cases we deal with objects derived from their parents. These objects-descendants are playing in modern science and in the evolution of civilisations an increasingly role. Their importance is first of all connected with a possibility to purposefully design living natural objects at the level of the genotype (of the micro-world) which largely determines the characteristics of individual-objects at the level of the phenotype (of the macro-world). Such designing is a delicate, time-and effort-consuming work which is called 'hybridization', i.e. uniting heterogeneous heredities [3] in one organism.

Natural 'hybridization on the Earth has been observed for a very long time whereas a possibility of artificial hybrids was first offered by the German scientist R. Kamerarius (1694). The English researcher T. Fergild (1694) was first to carry out artificial hybridization of plants. And G. Mendel in 1865 formulated the laws of domination, fission and independent combination in genetics as a science and motivated the need for the hybridologic analysis for studying the mechanism of transferring hereditary features (genes) [3].

Since the middle of the 60 s of the 20th century the 'genetic paradigm' has been actively used, for instance, in geology for studying the hybrid mountain rocks, in linguistics for studying hybrid languages having genetically heterogeneous lexicons, morphological and syntax models as well as in technical sciences – computer science where hybrid computing systems and hybrid microchips were developed, as well as in the theory of control in the form of hybrid systems (GS) and HYIS.

Hybrid intelligent systems were announced in 1990-1995 in the books [32,33] and essentially coincide with 'intelligent hybrid systems' [24] and 'hybrid integrated systems' [25], 'hybrid intelligent adaptive systems' [28]. The use of the term 'intelligent' in combination with 'hybrids' is marking our overcoming the limitations of analytical and statistical knowledge [13] with which GS are working and the application of which in the theory of control has a very long history. His also means integration of these into other knowledge types and technologies of artificial intelligence - expert systems (ES [17], genetic algorithms [36], artificial neural networks (ANN) [36], fuzzy systems (FS) [36], case-based systems and others. The above integration provides as multi-aspectness of studying of human intellect, social nature of generation, evaluation and making decisions hence the class of problems which are solved by hybrids is widened.

In the world practice of information technologies today HYIS is understood as a system in which more than one method of imitating intellectual activity of a person is used for solving a problem. Several most important papers on HYIS [10, 24,26,27,29,30-33] have been published in the last ten years.

In spite of the successes of HYIS during 90 s, the process of their creation is rather the creative work of a 'genetic-informatic' person in his unique workshop, than scientifically motivated hybridization widely used for solving of practical problems. Though the hybrid is a motivated combination of advantages of autonomous methods, in the unfavourable case, it can contain all their weaknesses only. This is happens, because very often ANN and fuzzy logic as autonomous technologies are still erroneously applied in practice. It is quite likely possible expect that these mistakes will be also present in HYIS as this new technology will be more and more accessible. Such situation is explained by the fact that there isn't generally accepted terminology, by the absence of conceptual models and formalisms of hybrids, by deficit of approaches and technologies of HYIS development.
One of such approaches is projected in \[24,32,33\], where the authors research the pluses and the minuses of a certain group of methods with a view to reach perfection for one of them at the expense of advantages of the others. We will call this the 'structured' approach to hybridization. It consists in that the developer selects a structure ensuring to the hybrid the properties, which are only potentially better than those of each of the parents do separately. However it does not mean that such HYIS will give the best problem-oriented, i.e. that it will be adequate to the problem solved.

In \[11,12,30,31\] the other, original approach was formulated which emphasises, while hybridisation, analysis a problem and synthesis of the structure of HYIS taking into account the advantages and disadvantages of autonomous methods. We call such an approach and the technology implementing this approach as 'Problem-Structured' hybridization. This PS-technology combining the system analysis of a problem and the synthesis of the method of its solving by selecting the HYIS structure is considered in this paper at the conceptual level.

3. Analysis of a heterogeneous problem

The ontology, which we have created, has shown that from 1960 till 2000 little changed in theoretical problem models. With the enviable consistency, a problem is interpreted in the same way as it was offered at the beginning of the 70 s by the specialists on operations research R.Akof and M.Sasieni \[1\]. Recently the accents are being shifted very slowly onto the 'subproblem selected within a given problem' \[17\]. This occurs synchronously with the development and usage of ES. This, in its turn, is connected with the fact that scientists in the knowledge engineering are facing difficulties of solving 'not a toy', 'simple', but 'practical', 'complex', 'much and specifically complex' problems \[16,35\], appearing everywhere where we deal with systems' functioning depending on many heterogeneous variables: deterministic, stochastic, precise and fuzzy linguistical, as well as variable relations. Direct effect of heterogenuity of variables \[2\] is its change from the area of 'simple', which we call 'homogeneous' to the heterogeneous area of 'complex' problems which we call 'heterogeneous' problems, displacing the accents in their analysis, modelling of understanding and solving, onto characteristics, which are to a greater extent determined by internal composition and structure, requiring principles of the system analysis.

Below we give the conceptual models of homo- and heterogeneous problems \(2,3\) based on the conceptual model of a problem \[14\]:

\[
\pi = \langle G, D, C \rangle,
\]

where: \(G\) - ultimate goal (result) of problem solving; \(D\) - initial data, meeting the requirements of necessity and sufficiency (fullness) for obtaining the result; \(C = \langle m, a, p \rangle\) - conditions (known or which are still to be determined) defining more precisely the relation between \(D\) and \(G\) and reflecting how \(D\) is transformed into \(G\); \(m\) - the solution method (pointing it out or the description thereof); \(a\), \(p\) - the algorithm and machine program of problem solving accordingly.

Model (1) shows a situation (which existed for many years) of abstracting from the internal essence of a problem in mathematics, artificial intelligence, operations research when they used the idea of the individual, non-systematic and asocial intellect \[21\]. The distributed knowledge and collective efforts paradigm substituted this idea at the beginning of the 90 s. This and the actual hybridological analysis and hybridization in the theory of control and computer science requires some revision of the term 'problem'. Below we define more precisely formula (1) by introducing the conceptual model of a homogeneous problem (in expressions 2 and 3 indications are given at the verbal level):
\[ \pi^h = \langle G^h, D^h, C^h, K^h, O^h \rangle, \]  
(2)

where: \( G^h, D^h, C^h \) - purpose, initial data and conditions of \( \pi^h \) accordingly; \( K^h \) - classifier of the problem, defining the class of the problem (of accounting, checking, analysis, normalising, forecasting, planning, regulation, organisation) and the class of the variables which it is necessity and sufficiently to manipulate for understanding and solving of \( \pi^h \) (deterministic, stochastic, fuzzy or precise linguistic, genetic); \( O^h \) - problem specifier, which includes the identifier of the problem, knowledge about the subject (for instance, an expert) and causes of \( \pi^h \) solving, knowledge about the relationships of the given \( \pi^h \) with other homogeneous problems falling into one and the same \( \pi^u \) (we neglect the relationships between \( \pi^h \) and \( \pi^h \) of the other \( \pi^u \)), as well as belonging of \( \pi^h \) to a certain heterogeneous problem \( \pi^u \).

Model (2) takes into account the knowledge about the class of the problem, specifies the variable, it is subject-oriented and considers a problem as an element of a more complex object which is a heterogeneous problem:

\[ \pi^u = \langle G^u, D^u, C^u, K^u, O^u, \Pi^u, R^{uh} \rangle, \]  
(3)

where: \( G^u, D^u, C^u \) - purpose, initial data, conditions of the \( \pi^u \) accordingly; \( K^u \) - classifier; \( O^u \) - specifier, which includes the identifier of the \( \pi^u \), knowledge about the subject (for instance, decision-maker) and the causes of \( \pi^u \) solving; knowledge about the relationships of the given \( \pi^u \) with other heterogeneous problems, about the operations, executing the decision of \( \pi^u \) and the evaluation of its results; the set of the evaluations of the results of the decisions of \( \Pi^h \); \( \Pi^u = \{ \pi^u_1, \pi^u_2, ..., \pi^u_{N_u} \} \) - the set of the decompositions of \( \pi^u \); \( \pi^u_i = (\Pi^h, \tilde{r}_i) \) - the decomposition of \( \pi^u \) by the relation \( \tilde{r}_i \in \tilde{R} = \{ \tilde{r}_1, ..., \tilde{r}_{N_u} \} \); \( \Pi^h = \{ \pi^h_1, ..., \pi^h_N \} \) - the set of \( N_h \) homogeneous problems within \( \pi^u \); \( R^{uh} \) - the set of the relations of corresponding elements of \( \pi^u \) and \( \pi^h \), i.e. \( G^h \) and \( G^u \), \( D^h \) and \( D^u \), \( C^h \) and \( C^u \).

Consider the separate components (3) more precisely. The purposes \( G^u \) and \( G^h_1, ..., G^h_{N_h} \), and the initial data \( D^u \) and \( D^h_1, ..., D^h_{N_h} \) can be dissimilar in the general case. For instance, \( D^h_1, ..., D^h_{N_h} \) can be more explicated, but \( D^u \) more abstract. The conditions \( C^u \) and \( C^h_1, ..., C^h_{N_h} \) are distinguished in principle, since if for \( C^h_1, ..., C^h_{N_h} \) we know the \( m^h \), otherwise, for instance, subject-expert is incompetent, and \( a^h \) and \( p^h \) can be known, then for the \( C^u \) method \( m^u \), as well as \( a^u \), \( p^u \) are the target objects and the ones to be designed. If \( N_h = 1 \) then there is the singular case when the solvers \( \pi^u \) and \( \pi^h \) are the same person: \( (\pi^u, \tilde{r}_i, \pi^h) | \tilde{r}_i \) - 'whole-part', \( G^u = G^h \), \( D^u = D^h \), \( C^u = C^h \), \( K^u = K^h \), \( O^u = O^h \).

Finally, having regularised heterogeneous problems:

\[ W^u = \langle \Pi^u, R^u \rangle, \]  
(4)

where: \( R^u = \{ r^u_1, ..., r^u_{N_u} \} \) - the set of the relations on \( \Pi^u \), for instance, 'cause-effect', 'class-subclass', and others,
we will complete the formation of model $W^u$ of the problem world. Model (4) avoids terminological contradictions in ontology of the world of the problems and explains the failure of attempts to model problems. Separate parts from $\pi^u$ 'cut out' while doing so, which can be imitated within the framework of an autonomous method supported by this or that scientific school. Such obviously simplified models of $\pi^u$ when the problem structure is not taken into account (or strictly speaking, the initial problem $\pi^u$ has not been solved) after 'successful' laboratory tests go into practice without any prospects to be applied. The solver as usual has to solve a more general (whole) problem $\pi^u$ and the computer solution scheme 'does not fit' into the solver's creative process. Finally, $W^u$ possesses flexibility, and is open for modification (adding and removing $\pi^h$) and the problems world as a whole (adding and removing $\pi^u$).

The decomposition of a heterogeneous problem in the world $W^u$ causes corresponding 'system response' in the world of autonomous and integrated methods of modelling $W^u$ [11] in the form of the designing process (synthesis) of the structure on the basis of a set of the 'genetic' material, i.e. two or more autonomous models (we will call this a 'heterogeneous model field'), which have been created by using a certain autonomous methods.

4. Synthesis of the method of heterogeneous problem solving

For the synthesis of HYIS as method $m^u$ of solving the heterogeneous problem $\pi^u$ in $W^u$ we will choose set $\{m^u\}$ [10]. For instance, homogeneous problems of forecasting, recognition, classification, generalising, identification are solved by artificial neural networks ($\alpha^h_1$). Problems of recognition, searching, diagnostics, choice, evaluation, analysis of risk, prediction and learning are solved by fuzzy systems ($\alpha^h_2$). Problems of mass service, reception capacity, reliability are solved by simulation statistical modelling ($\alpha^h_3$). Problems of interpretation, prediction, diagnostics, checking, debugging, briefing are solved by expert systems ($\alpha^h_4$), but problems of playing, combinatorial ones, those of optimisation, searching, placement, development, improvement are treated by genetic algorithms ($\alpha^h_5$).

Let us choose set $\{m^h\}$ restricting our synthesis to coarse-grained hybrids [37]. Then we can create the conceptual model of HYIS in the 'thing ($\alpha$)-property ($\beta$)- relation ($\rho$)' language of the knowledge domain description in the systems theory [22]. In this language $\alpha$, $\beta$ and $\rho$ are:

$$\alpha = _{\text{def}} (\rho(\beta_1, ..., \beta_{N_\beta})), \quad \beta = _{\text{def}} (\rho(\alpha_1, ..., \alpha_{N_\alpha})), \quad \rho = _{\text{def}} (\alpha(\beta_1, ..., \beta_{N_\rho})).$$ (5-7)

Definitions (5-7) confirm that any thing is a system of qualities, a property is something inherent to a class of things, but a relation is a new thing with certain properties.

As any system, HYIS consists of two elements (components) as a minimum which can carry some functional sense (or can organise control) and can solve the heterogeneous problem $\pi^u$. Then it is possible to present functional component $\alpha^h_1$ as follows:

$$\alpha^h_1 = _{\text{def}} (\rho^h(\beta^h_1, \beta^h_2)) | i = 1,2, \quad \text{or} \quad \alpha^h_i = _{\text{def}} (\rho^h(\beta^h_1, \beta^h_2, \beta^h_3)) | i = 3,4,5.$$ (8,9)
where: \( \beta_1, \beta_2, \beta_3 \) – input, output and state of \( \alpha^h \) accordingly; \( \beta^s \), \( \beta^h \), \( \beta^t \) – relations of functioning of \( \alpha^h \), \( \alpha^s \), \( \alpha^t \) at the time of \( t \) of the model.

The differences of (8) and (9) are explained by the semantics of \( \beta_1, \beta_2, \beta_3 \) : the functioning of \( \alpha^h \) and \( \alpha^s \) (8) is 'not transparent'. The intermediate states of the simulation process cannot be interpreted in the terms of heterogeneous problem solving and observation of behaviour of \( \alpha^h \) and \( \alpha^s \) is not informative. Unlike \( \alpha_1, \alpha_2 \) components \( \alpha_1, \alpha_4, \alpha_5 \) are of 'behavioural' nature (9), i.e. their state can be observed and interpreted.

The input, output and state of \( \alpha^h \) are homogeneous, i.e. given in one class of variables (2). There is an exception for deterministic variables, which can be used together with other variables. HYIS can include technological components \( \alpha^t \| j = 1, \ldots, N_t \) along with functional components. These \( \alpha^t \) are used for organising control in \( \{ \alpha^t \} \) and for exchange of information between \( \{ \alpha^t \} \).

To synthesise HYIS (\( \alpha^u \)) implementing method \( m^u \), we will introduce integration relation \( \rho^u \) in sets \( \{ \alpha^h \} \), \( \{ \alpha^s \} \), \( \{ \alpha^t \} \), \( N_h \), \( N_s \), \( N_t \), \( N_h \geq 2, \exists \alpha^u \{ \alpha^t \} = \emptyset \). This relation \( \rho^u \) determines the structure and forms a whole from heterogeneous parts. Relation \( \rho^u \) is determined by decomposition \( \pi^u \). It plays a principal role in hybridisation. So, in [11] we chose nine classes of \( \rho^u \) : extraction \( \rho^u \), evaluation \( \rho^u \), inclusion \( \rho^u \), addition \( \rho^u \), comparison \( \rho^u \), argumentation \( \rho^u \), control \( \rho^u \) and knowledge mapping \( \rho^u \), as well as role relations \( \rho^u \).

The input of HYIS is initial data \( D^u \) of problem \( \pi^u \), which will be sent to the input of one or several \( \alpha^h \), in accordance with \( \pi^u \). Each component herewith 'takes only its own variables'. The state \( \alpha^u \) at a moment of the model time \( t \) is a vector \( \beta^u (t) = (\{ \beta^h_1 \}, \ldots, \{ \beta^h_5 \}) \), where: \( z = 1, \ldots, 5 \) - class of the variable shown in (2), i.e. if \( z = 1 \) then \( \{ \beta^h_1 \} \) is a set of deterministic variables, if \( z = 2 \) then \( \{ \beta^h_2 \} \) represents stochastic variables, etc. Each \( \alpha^h \) changes only components of the vector of the state corresponding to its \( K^h \). At a certain moment \( t \), determined by \( \alpha^t \) or coinciding with the moment of time when \( \alpha^h \) stops functioning, 'homogeneous functioning' of the current \( \alpha^h \) is broken and \( \alpha^u \) jump over to the state determined by another \( \alpha^t \) at \( j = 1, \ldots, 5 \). At the \( t \) moment, also defined by \( \alpha^t \) or \( \pi^u \), result \( G^u \) of solving problem \( \pi^u \) is given.

Then the conceptual model of HYIS looks as follows:

\[
\alpha^u =_{\text{def}} \{ \rho^u \{ \beta_1, \beta_2, \beta_3 \}, \rho^u \{ \beta_2, \beta_3 \}, \rho^u \{ \beta_1, \beta_2, \beta_3 \} \}, (10)
\]

where: \( \rho^u \) - relations of functioning of \( \alpha^u \); \( P_{11}, P_{22}, P_{33} \) - set of relations of the input, state and output of \( \alpha^u \) and the input, output and state of \( \alpha^h \) accordingly.

Model (10) determines the fact that HYIS is a system having certain architecture of information exchange, having the input, the output and functioning in the heterogeneous space of states. We call such functioning as the 'hybrid simulation process'. If HYIS solves a decision
making support problem, there can be some analogy in accordance with which the components are simulating the solution of homogeneous problems \( \pi^b \) by experts, and \( \alpha^u \) are imitating collective solution of \( \pi^u \) under the auspices of the decision-maker.

5. PS-technology

It is possible to offer the problem-structure technology of hybridization in accordance with models (2-4) and (10). First of all, the developer executes the analysis and the decomposition of problem \( \pi^u \). Then he develops and (or) uses homogeneous models \( \{\hat{m}^b\} \) for forming \( W^u \). Let us assume that there will be \( N_m \) such functional models (components). So, the heterogeneous field of dimensionality \( N_m \) corresponds to \( \pi^u \). The nonblank subsets (they can be one-element) which correspond to \( \pi^b \), have been chosen in this field. After that we develop table \( T^u \) of hybrid strategies. In \( T^u \) problems \( \pi^b \) are interrelated with the help of \( \rho^u \), which substitute the relations of decomposition \( R \) (hereby we restrict oneself to the case when between two \( \pi^a \) there is only one relation \( \rho^u \)). As far as the input, the state and the output \( \alpha^u \) are heterogeneous, i.e. there is a combination of values of variables from different classes. After that relations \( R^u \) are to be determined (3). Let \( R^u \) be given. So far as more than one models \( \hat{m}^b \) can correspond to problem \( \pi^b \) in decomposition \( \hat{\pi}^u = (\Pi^b, \hat{\pi}^u) \), the procedure of evaluation and choice of autonomous models for each three-tuple \( (\pi^b, \rho^u, \pi^h) \) is included in hybridization. This procedure is realised as follows. Each \( \hat{m}^b \) must be a priori evaluated on the scale of 0-1 by experts to check its adequacy to the intervals of values of the most important variable components \( \hat{\beta}^u (t) \) of the state \( \hat{\pi}^u (t) \). The fuzzy system (FS1) is adjusted using expert evaluations. Identifier \( \pi^h \) and \( \hat{\beta}^u (t) \) set of variables are sent to the input of FS1 while synthesising HYIS. And desirable evaluation can be obtained at the output.

Let \( \hat{\pi}^u = (\Pi^b, \hat{\pi}^u) \) be a tree. Then the procedure of evaluation and choice of \( \hat{m}^b \), as well as design of \( m^u \) looks as follows (a fragment of this procedure is given in Fig. 1): 1. Start, \( i = 1 \); 2. Choose the set of the three-tuples \( \Pi^h = \{(\pi^h \hat{\pi}^h) \}| \varphi = 1, \ldots, N\varphi \) from \( \hat{\pi}^u \). Each \( \pi^h \) is in the sheet of

![Figure 1. The fragment of the procedure of evaluation, choice and design of the solving method of heterogeneous problem](image-url)
3. \( j = 1 \), \( \Omega_j = \emptyset \); 4. Choose the next three-tuple sub- \( j \) from \( \Pi^h \); 5. If \( \pi^h \) is the root, then go over to 6, otherwise go over to 7; 6. Initialise list \( L_j \) for the three-tuple sub- \( j \) marking its elements of \( \varepsilon_j^l \) with the models of problem \( \pi^h \). Using FS1, get the evaluations of the models \( \{ \tilde{m}^h_q \} \) and choose the element with the maximum value of evaluation and enter \( \tilde{q}^h \tilde{m}^h_{\Pi^h} \varepsilon \); 7. Go over to 8; 8. Initialise matrix \( E_j \) for the three-tuple sub- \( j \), marking its \( q \) line and \( l \) columns with models \( \tilde{m}^h \) of the \( \pi^h \) problem (the columns are marked with \( \{ \tilde{m}^h_q \} \), but the lines - with \( \{ \tilde{m}^h_l \} \) ). Supplement \( \Omega_j \mid j = 1, \ldots, N_{\Omega_i} \) with matrix \( E_j \), i.e. \( E_j \in \Omega_i \); 9. \( i = N_{\Omega_i} + 1 \)? If 'no', then \( j = j + 1 \) and go over to 4, otherwise delete the sheets on \( \pi^\delta \) and check if \( \pi^\delta \) contains only the root now. If 'yes', then go over to 9, otherwise \( i = 1 \) and go over to 2; 10. Choose \( E_j \mid j = 1, \ldots, N_i \) from \( \Omega_i = \{ E_1, \ldots, E_{N_i} \} \). Using \( T^\nu \) actuate only those elements \( \varepsilon^l_{\rho} \) in \( E_j \) for which the \( \rho^\nu \) relation exists between \( \tilde{m}^h_q \) and \( \tilde{m}^h_l \). This is shown by the strikethrough of the cell of the matrix \( E_j \) in Fig. 1. If \( \{ \tilde{m}^h_q \} \) have already been valued, then put these evaluations into the denominators \( \varepsilon^l_{\rho} \) of the fractions (elements) \( \varepsilon^l_{\rho} \) and go over to 11, otherwise using FS1 carry out the evaluations of models \( \{ \tilde{m}^h_q \} \) of the \( \pi^h \) problem, putting the evaluations into the denominators \( \varepsilon^l_{\rho} \) of the fractions \( \varepsilon^l_{\rho} \); 11. Model the solution of \( \pi^h \) on each of \( \{ \tilde{m}^h_q \} \) and use the obtained values of the outputs \( \tilde{m}^h_q \) to use as the inputs of \( \tilde{m}^h_q \). Using FS1, carry out evaluations of the models \( \{ \tilde{m}^h_q \} \) of the \( \pi^h \) problem, entering the evaluations into numerator \( \varepsilon^l_{\rho} \) of the fractions \( \varepsilon^l_{\rho} \). By formula \( \max \sum_{\rho} (\varepsilon^l_{\rho} + \varepsilon^l_{\rho} - (\varepsilon^l_{\rho} - \varepsilon^l_{\rho})) \) choose the three-tuple of models \( \{ m^h_{\rho} \} \times y = 1, \ldots, N_m \) adequate to \( \Pi^h \) and put it into list \( m^\nu \); 12. \( j = N_i + 1 \)? If 'no', then \( j = j + 1 \) and go over to 10, otherwise to 13; 13. \( i = N_{\Omega_i} + 1 \)? If 'no', then \( i = i + 1 \) and from the subsets of the models corresponding to problems \( \{ \pi^h \} \), delete the models which are not represented in \( \{ \tilde{m}^h_q \} \) within the list of \( m^\nu \) and go over to 9, otherwise go over to 14; 14. Initialise the HYIS in accordance with \( m^\nu \); 15. 'End'.

Then modelling of the solution of \( \pi^\nu \) is carrying out, using HYIS and then the results are analysed. The stages of the PS-technology can be executed in the iteration mode before getting the desired results. The technology under consideration has been realised in the AGRO-system software.

6. Homogeneous and heterogeneous modelling in the PS-technology

The heterogeneous problem of strategic planning of the harvest and agricultural technologies for winter wheat and barley cultivated for the agricultural companies of the Kaliningrad region of the Russian Federation is solved in the AGRO-system. Strategic planning is a vitally important type of management activity. It is realised in autumn when agricultural works are over. It is carry out by solving the heterogeneous problem of planning of harvest and agricultural technologies for the spring and summer period of the next year. The problem consists in calculating the main planned economic factors of an agricultural company and in developing agricultural technologies, forecasting the harvest in the area with high-risk farming [12]. The results considered below were obtained using the Ladushkin Company Ltd as an example, the latter being one of the largest
Network with forward propagation, a fuzzy system and a neuro-fuzzy (NF) hybrid for solving of analytical models well known in the field of agricultural. Three ES for solving of the problems of the second group. Alongside with author's models, were used several of modelling in the biological stratum. The heterogeneous field of seven models was developed for the first group are solved by the information-retrieval system, which uses in its functioning the results of modelling in the biological stratum. The heterogeneous field of seven models was developed for solving the problems of the second group. Alongside with author's models, were used several analytical models well known in the field of agricultural. Three ES for solving of the $\pi_1^h - \pi_3^h$ problems, the analytical model (algebraic equations - AE) for solving of $\pi_3^h$, an artificial neural network with forward propagation, a fuzzy system and a neuro-fuzzy (NF) hybrid for solving of $\pi_1^h$ are included to this heterogeneous field.

The lines of the tables meet the conditions of the experiments marked on the OX axes on the graphs. The first value is the humus level of the soil (1- 'good', 2- 'average', 3- 'weak'). The second value is the temperature of air and the quantity of precipitation (1-6, 1: 'favorable for cultivating winter wheat'; 7-9 - 'disadvantageous'). The columns of the tables correspond to the strategies of modeling: 1- ($\pi_1^h$ - ES) $^4 \rho_s^f (\pi_2^h$ - ES) $^4 \rho_s^a (\pi_3^h$ - ES); 2- ($\pi_1^h$ - NF) $^4 \rho_s^f (\pi_2^h$ - ES) $^4 \rho_s^a (\pi_3^h$ - AE); 3- ($\pi_1^h$ - FS) $^4 \rho_s^f (\pi_2^h$ - ES) $^4 \rho_s^a (\pi_3^h$ - AE); 4- ($\pi_1^h$ - FS) $^7 \rho_s^a (\pi_2^h$ - ES) $^4 \rho_s^a (\pi_3^h$ - AE); 5- ($\pi_1^h$ - ANN) $^4 \rho_s^a (\pi_2^h$ - ES) $^4 \rho_s^a (\pi_3^h$ - AE).

Figure 2. The results of comparative analysis of homo- and heterogeneous modeling

The experiments were executed for the quality comparative analysis of homogeneous and heterogeneous modelling. The statistical data on the harvests of winter wheat at the Ladushkin Kaliningrad agricultural institutes and experimental stations. We also use the expertise of Kaliningrad agricultural institutes and experimental stations.

The problem was decomposed into eight subproblems distributed into two strata: the production stratum and the biological one. To the first group we referred the problems of rational organisation of production. The second includes five subproblems of forecasting: the conditions of sowing ($\pi_1^h$); harvest ($\pi_2^h$); doses of fertilisers and microelements ($\pi_3^h$); periods of entering the fertilisers and microelements; spreading of diseases, the vermin and weeds. The problems of the first group are solved by the information-retrieval system, which uses in its functioning the results of modelling in the biological stratum. The heterogeneous field of seven models was developed for solving the problems of the second group. Alongside with author's models, were used several analytical models well known in the field of agricultural. Three ES for solving of the $\pi_1^h - \pi_3^h$ problems, the analytical model (algebraic equations - AE) for solving of $\pi_3^h$, an artificial neural network with forward propagation, a fuzzy system and a neuro-fuzzy (NF) hybrid for solving of $\pi_1^h$ are included to this heterogeneous field.
The errors (the percent from the actual harvest) of the homogeneous and heterogeneous modelling in three variants of the soil and nine variants of weather conditions for five modelling strategies are shown in the tables in Fig. 2 (bold type was chosen to mark the minimum error used while the generating the graphs). The comparative analysis of the results of experiments has shown that the experts have enough knowledge for forecasting with the errors from 2-h before 5 % for soils with a good humus layer and for favourable weather conditions (Fig. 2 a). However hybrid modelling already gives the better results for disadvantageous weather conditions. The accuracy of heterogeneous planning is higher for soils with average and bad humus level (Fig. 2 b, c) and bad weather conditions. So, it is possible to make the conclusion that hybrids give an error in the second and the third series of experiments, which is 3 times smaller than autonomous models and heterogeneous modelling. The results of experiments have also shown that the PS-a technology will be easily to programmable, transparent, and will the time spent by the developer and it can be used for HYIS development.

7. Conclusions

Our research demonstrates that heterogeneous (hybrid) cognitive structures of analytical, statistical and logical-linguistical knowledge are formed and stored in the memories of the experts. And their reasoning while motivating and solving heterogeneous problems using this knowledge is a kind of 'soft computing'. The heterogeneity of cognitive structures and soft computing of reasoning are observed in languages of the professional activity of the specialists, where 'mixed' analytical dependencies in the form of formulas or graphs, tables of statistics, precise and fuzzy linguistic variables. The experts, explaining or solving the problem, 'switch' over to different reasoning schemes: calculations, statistical conclusions, logical argumentation, approximate evaluations and manipulating by images. We call these effects 'heterogeneous problem solving' and 'heterogeneous reasoning'.

The PS-technology considered in this paper is oriented at working with these effects exactly. Its main principles are: first, consideration of the world of practical problems as a world of homogeneous and heterogeneous problems, second, analysis and decomposition of heterogeneous problems and third, synthesis of the HYIS structure adequate to heterogeneities. That is associated with designing of the method of problem solving on the basis of the set of the models and other tools available for the developer. The PS-technology does not reject autonomous models and methods. Moreover it considers them to be the first and natural stage of evolution of the worlds of problems and methods and acquisition by the developer of corresponding experience. However this technology offers and makes it possible to take a step forward - to integrate heterogeneous models into one whole. This whole is a hybrid intelligent system for implementation of the principle of self-organising in cybernetic systems. Such integration is a guarantor of raising the model adequacy to the original. And that is convincing show by our experiments. Such integration is the way to achieve of transparency, greater expressive power, power of reasoning of intelligent systems for the development of applications which are fuller and can be created with smaller efforts than systems created on the basis of autonomous models.

8. References


