COGNITIVE MODELLING AS THE INSTRUMENT IN THE COURSE OF KNOWLEDGE OF LARGE SYSTEM

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***Abstract**: In this report we observe the possibilities offered by cognitive methodology of modeling of complex systems (social and economic, sociotechnical) and the developed software from positions of process of knowledge of complex object, and also extraction of different aspects of knowledge from the data about an object. The maintenance and program of researching of complex systems are set in the form of model of a metaset of the researching system, which distinctive feature is the description not only of big system and its interaction with environment, but also introduction in a metaset of "observer" that allows to build methodology of research and decision-making taking into account development of process of knowledge of object in consciousness of the researcher. Generally the model of the complex system is under construction in the form of hierarchical dynamical cognitive model. The mathematical model is exposed to formal researches. Connectivity, complexity, controllability, stability, sensitivity, adaptability and other properties of model on which the conclusion about presence (absence) of similar properties at studied big system becomes are analyzed. In the course of research self-training of the analyst ("observer") takes place by using developed toolkit for extraction of knowledge of object and decision-making.*

***Keywords**: The expert, extraction of knowledge, cognitive, complex system, model, behavior, structure, decision-making, information technology.*

***ACM Classification Keywords**: I.2.0 General - Cognitive simulation*

Introduction

The certain experience of the work which have been saved up during a number of years in sphere of cognitive modeling of large ("big") systems (Gorelova, etc. (2002), (2005), (2006), (2007), (2009), (2010)) allows to understand both the developed and being developed formal models and methods of research of difficult systems as one of very effective tools of their knowledge and usage of results of this knowledge in practice. Application of cognitive approach is understood in this case in a context of continuous "interaction" of results of knowledge by the subject of difficult object and the object itself, it is important to consider application, at least, in a view of three positions: first - the "utility" ("harm") of consequences of accepted decisions for object, then from theoretical positions of reception of new knowledge and from positions of "utility" of this knowledge for the subject.

In the first case it is especially important to understand "the risk of the human factor". Considering the weakly structurance of problems of the big systems, difficultness of "correct" gathering and processing of the information about them, "correctness" of the aim of research (an explanation of the mechanism of the phenomena of forecasting, management, generating of administrative decisions, etc.), it is necessary to take in a view the necessity to have the convenient tool for research and decision-making support.

By this time, many tool means of support of decision-making, including, various intellectual systems are developed. But thus it is not given special attention to a question how to consider process of knowledge during research and accumulation of knowledges, feedback between results of knowledge an object by the subject is not formalized. The problem of understanding of process of knowledge of difficult object and "management" of this process thereby becomes complicated. Proceeding from the aforesaid developing methodology of cognitive modeling is a product of generalization and usage of achievements of the theory of systems and the system analysis [Volkova, Denisov, 2005], researches of operations, statistics, mathematical programming, the theory of management, the theory of decision-making, intellectual systems, etc. We stand on a position that now one theory, one method (or even the group of methods) don't allow to consider all aspects of problems of the big system, more often the part of the phenomena on which the attention of the researcher is directed or which was defined by the social order is considered. But thus there are many questions. For example, how the analyst has ideas of application of knowledge from this or that area to studying of concrete object? How, in what sequence and why they are applied? How all it directs knowledge process? Whether it is possible to operate this process? And to what results it can lead? It is possible to search for answers to these questions, leaning, including, on collected results of cognitive researches of the big systems, for example, [Trahtengerts, 1998], [Maxims, Covrege, 2001], [Kulba, 2002], and also on own researches of regional social and economic systems as a whole, and separate subsystems.

In section 2 the basic used concepts and definitions are resulted; section 3 is devoted a question of formalization of process of research of difficult object; in section 4 short representation of the system problems forming methodology of cognitive modeling is given. In section 5 the methodology scheme of cognitive modeling is presented.

1. The basic concepts

In the given work a number of the widespread concepts which sense it is necessary to explain according to spent cognitive researches is used.

«*The big system*» – is understood in sense, for example, of the researches of Institute of problems of management of the Russian Academy of Sciences (Management of the big systems). The big system («*large-scale systems*») is «*the complex system*», the term used in many works (for example, [Casti, 1979], [Klir, 1988]).

First, it is characteristic for the big systems to have a large quantity of elements and communications, interactions between them, but it is not enough for this sign. It is essential that the complexity of the structure formed by these elements – multilayered, hierarchical, etc. Often weakly enough interactions raise complexity of system. Secondly, it is a dynamics of system [Malinetsky, Potapov, 2000], complexity of its behavior. Probably, even unpredictability of behavior. Thirdly, there are regularities inherent for such systems which yet all are not studied yet up to the end.

Let"s name the major of these regularities [Volkova, Denisov, 2005]: ones of interaction of parts and whole (integrity, integration); regularities of hierarchical orderliness of systems (communicativeness, hierarchy) - this group of regularities is closely connected with one of wholeness, with a dismembering of a whole on parts, interaction of system with environment, i.e. abovesystem, and the subordinated systems; regularities of functioning and development of systems (historicity, self-organizing); laws of practicability of systems (equifinality, the regularity of a necessary variety, potential efficiency).

Fourthly, there are problems inherent for such systems: weakly structural and not structured (systems with the structured problems less concern to difficult, than others). *The structured problems* are those ones in which essential dependences are clearly expressed and can be presented in numbers or symbols. These are problems "quantitatively expressed"; the decision of problems of this class uses methodology of researching operations. *Non structured problems* - are those ones that expressed in qualitative signs and characteristics, they don't give in to the quantitative description and numerical estimations. Researching of such problems is possible by using the probably heuristic methods, and there is absence of possibility to apply logically ordered structures of searching decisions. Weakly structured problems are characterized by presence both qualitative, and quantitative elements. Uncertain regularities are not giving in tthe quantitative analysis, dependence, signs, characteristics tend to dominate in these mixed problems. The majority of the most challenges economic, technical, political, strategic, etc. character problems concern to this class. «Weakly structurance » concerns more likely an information component - degrees of knowledge of the person, making the decision (the expert, an analyst). «Structural Degree» of the problem can be connected s with an information situation.

It is offered to allocate following situations: 1) basic uncertainty (the quantum mechanics); 2) the uncertainty generated by the general great number of objects, included in a situation (for example, 109); 3) the uncertainty caused by a lack of the information and its reliability owing to technical, social and other reasons; 4) the uncertainty generated by too high payment for definiteness; 5) the uncertainty generated by the decision-maker owing to a lack of its experience and knowledge of factors, influencing decision-making; 6) the uncertainty connected with restrictions in a situation of decision-making (time, the finance, etc.); 7) the uncertainty caused by behavior of environment or the opponent, influencing decision-making process.

All aforesaid characterizes the big system and its complexity. In the course of system knowledge there is «an uncertainty disclosing». And the more successfully, than more absolutely the used by an analyst tool is, the more above his professionalism and understanding of own process of knowledge are then, whenever possible, it is to "operate" this process. «Uncertainty Disclosing» is understood as process of cognitive structurizations of knowledges of the expert. Formalization of this process can be begun with formalization of concept of the "system" and workings out of model of research.

2. Formalization of the problem research

It is possible to track evolution of using categories of the theory of knowledge (cognitive theory) in researching activity [Volkova, Denisov, 2005], [Gorelova, Zaharova, Radchenko, 2006]: originally models (especially formal) are based on the account only elements and communications, interactions between elements; further elements, communications, the purposes (searching methods of the formalized representation of the aim – criterion function, criterion of functioning etc.) are considered; then - elements, communications, the purposes and more and more attention to the observer, the person which makes experiment, models, makes decisions; as a result - the product of knowledge (model) forms process of knowledge, and as a result of the next stage of process of knowledge – there is a model again etc.

The maintenance and the program of research of difficult systems can be set in the form of *model of a metaset of the system of research* (the metamodel offered by Kulby in his works became initial):

$$M = \{M_O(Y, U, P), M_E(X), M_{OE}, M_D(Q), M_{MO}, M_{ME}, M_U, A, M_H\} \quad (1)$$

Where MO (Y, U, P) – is the identifying model of system (object model), in which vector Y – endogenic variables $y \in Y \subseteq E^m$, characterizing a phase condition of object, U – a vector of operated variables $u \in U \subseteq E^r$, P, P – a vector of the allocated resources $p \in P \subseteq E^s$; MO (Y, U, P) = {MΦ, Stat}, Stat – statistical models; MΦ – the modified parametrical vector count; ME – environment model, X – exogenic sizes; Mo_E = {$M_{YS\chi}$, M_{YS} } – model of interaction of object and environment ($M_{S\chi}$ – models of communication with environment in an input, M_{YS} - models of system communication with environment on an exit); $M_D(Q)$ – model of behavior of system, Q – revolting influences, M_{MO} and M_{ME} – models of measurement of a condition of system and environment; MU – model of the managing director of systems (doesn't join in a metaset if object research problems dare only); A – a rule of a choice of processes of change of object; M_H – model of "observer" (the engineer-kognitiologa, the expert, the researcher). In this metamodel that it considers not only system, but also its environment, interaction with environment is essential. Besides, introduction in a metaset of M of "observer" allows to build methodology of research and decision-making taking into account development of process of knowledge of object in consciousness of the researcher.

Models of system, environment, their interaction is the cognitive models (cognitive cards); models of behavior of system are the impulse processes or scenarios of development of situations. Working out of such models is included into process of cognitive structurization of knowledge of the expert. Working out of a metamodel (1) fixes the purposes, research problems and decision-making, allowing to observe all the picture as a whole, without losing details. Depending on the purpose the concrete models making a metamodel are under construction. It is necessary to make an important conclusion: the decision of weakly structural problems in complex systems demands the interdisciplinary approach. In our researches this approach is realized by means of *cognitive modeling, cognitive associations* of isolated knowledge in various fields of knowledges.

So: the basic distinctive feature of our researches – *cognitive association* in system both known, and again developed methods and the models created in the process of knowledge of object by the subject. Cognitive association is the process occurring in consciousness of the expert. And -that this is the main thing! - it is carried out by the continuous, cyclic decision-making process by the expert supported by special tool means. We now are on a way of working out of corresponding supporting mathematical and program toolkit for this purpose [Gorelova, Zaharova, Radchenko, 2006]. Also we try to understand and explain, why and how such association occurs. And how can it be used practically. Probably, all it also is sphere of contact of various researches in area of cognitive sciences.

Now we understand under *cognitive modeling* is the decision of the interconnected system problems: working out cognitive models; the analysis of ways and cycles of cognitive models; the scenary analysis; decisions of opposite problems; observability and controllability of system; stability; complexity and connectivity of system; decomposition and compositions; optimization; forecasting; accidents; adaptations; self-organizing; sensitivity; decision-making. The book [Casti, 1979] became a starting point for allocation of interrelation of these system problems. First four problems are traditional enough in cognitive analysis, there are software for their realization (for example, program complexes "Situation", "Compass", "the WHALE", developed in ИПУ the Russian Academy of Sciences). Other problems, are those ones: that are a subject of our theoretical and practical workings out now.

3. Representation of the primary goals, models and methods in technology of cognitive

It is possible to track evolution of using categories of the theory of knowledge (cognitive theory) in researching.

Technology of cognitive modeling represents certain system of statement and the decision of the designated systemic problems directed on this or that of research objectives.

1) Working out of *cognitive model* is the most creative and weakly formalizing stage in activity of the researcher (a group of experts) of the big system. Partially formalization is possible at processing of the numerical data in the form of the statistical information by use of means of the intellectual analysis of the data (for example, Data mining). As sources of the information for definition of "qualitative" tops theoretical data can serve theoretical data in studied subject domain and the coordinated decisions of a commission of experts. It is necessary to pay attention to necessity of the "correct" name of top - unsuccessfully picked up names (concepts) deform results of research and can give answers not on those questions which have been put. A result of process of identification of difficult system at the first investigation phase is cognitive card G [Casti, 1979], [Maxims, Covrege, 2001], further it is offered to open this model, passing to hierarchical cognitive models or to system cooperating hierarchical dynamical cognitive models [Gorelova, Miller, Radchenko, 2006], [Gorelova G.V, Gorelova, I. S., 2007].

Where $JM\Phi_D$ - is the hierarchical count consisting of models in the form of modified parametrical vector functional counts [Roberts, 1978]; Gjk (St), $G_{j(k+1)}$(St), – is dynamical hierarchical cognitive models j – systems (j=1,2, …, N; levels k, k≥ 2, E = {e k, k+1} - set of arches between levels k) with reconstructed structure St depending on influence of environment; X (St) – changing parameters of tops cognitive cards; F (St) – changing functional communications between tops; q - space of parameters of tops, t – time; Rst – rules of change of structures.

If the developed model leans on the fundamental law, proves by the true experiment, due to it can be proved it's *adequacy* to displayed system or processes (situations) in system (model is adequate in moderately completeness of products of initial data and knowledge).

2) *The decision of a problem of the analysis of ways and cycles of cognitive models* is made by traditional methods of the theory of graphs. Allocation of ways of the various set length allows to track and interpret sequences of relationships of cause and effect, revealing their features and the contradiction. Allocation of cycles (positive and negative feedback) allows to judge structural stability (or not) systems.

3) *The scenery analysis* allows to judge about behavior of system, scientifically expect the ways of its possible development. The analysis is spent by results of pulse modeling (Roberts (1978)). For generating of possible scenarios of the development of a system in tops of cognitive card there are brought hypothetical revolting or managing directors to influence. At entering of indignations Qi (n) the question is investigated, «and what will be during the moment (n+1), if …?». The set of realizations of impulse processes is «the development scenario», specifies in possible tendencies of development of situations. The situation in impulse modeling is characterized by a set of all Q and values X in each step of modeling.

4) *The Decision of a return problem* - is a search of such values of operating influences Q which can provide the desirable scenario of development of system. For the decision methods of mathematical programming (linear, nonlinear) can be used.

5) Decisions of problems of *observability and controllability* of system are interconnected. *An observability problem* – a problem of definition of sufficiency of measurements of target variables for definition of unknown initial values of inputs. *The controllability problem* is a problem about possibility of change of inputs of system depending on observable exits (the cybernetic or administrative approach).

6) *Decisions of problems of stability*. Stability – is a multidimensional concept. In researches of social and economic systems the term "stability" designates many aspects, not always accurately defined (stability of a financial system, stability of the organization). In the theory of management a concept "stability" is accurately

defined, there are developed measures of stability of system («stability on Lyapunov», etc.). There are considered two aspects of concept "stability": stability of system under the influence of external indignations at the fixed structure of system, that is when only the environment changes, and stability of behavior of system at changes of structures of system – structural stability (small changes in system structure cause small changes in its dynamics).

7) *The problem of complexity and connectivity of system*. The concept "connectivity" of system arises together with concept system "structure". With disappearance of structural connectivity the system disappears. The mathematical description of a problem of the analysis of connectivity most successfully turns out in language of the theory of graphs and algebraic topology. Graphical models allow to understand better the system, interrelation of its elements, force of their influence. Models are convenient for the visual analysis of connectivity and give the chance to carry out the methods of formal analysis of the theory of graphs. The second approach is based on research of topological properties of graphs' model on a matrix of relations of cognitive cards, the so-called q-analysis of connectivity of simplicial complexes [Atkin, 1997], [Barcelo, Kramer, 1998], [Gorelova, Zaharova, Radchenko, 2006]. From these positions connectivity of system is an algebraic concept and its studying is conducted in language of algebraic topology. Concepts of connectivity and complexity of system mutually caused. There are considered: *structural complexity, dynamic complexity, computing complexity, evolutionary complexity; internal and external complexity.* In order the system to realize the set of kind of behavior without dependence from external hindrances, it is possible to suppress variety in its behavior, only having increased sets of managements (a principle of necessary variety of Eshbi). Such ability of system characterizes «*complexity of management*». The system can't be "universally complex". It can be difficult from one positions and simple from others. "Complexity" of systems often leads to the next: that is easier at first to study elements, system components, and then, on the basis of the received knowledges to try to understand system as a whole. Therefore the problem of the analysis of complexity of system is connected with problems of *decomposition and composition of a system*.

8) *Problems of decomposition and composition of systems*. Theory-graphical models allow to understand in many cases how it would be possible to carry out system decomposition on smaller blocks without loss of those basic properties thanks to which the system is a system. But there appears *a problem of the best decomposition of systems*. For finaly measured spaces of conditions there are proved theorems (Zhordana-Gyoldera, the Crone-roudza …) that any final group can be constructed of the fixed set of simple groups and this set of groups (the theory of groups) is defined unequivocally. Somewhat these theorems give the best decomposition of certainly measured systems. All that gives the chance, irrespectivly of complexity of behavior of a system, to analyze system, studying only rather simple objects which incorporate by certain rules.

9) *The optimization problem* - is a problem of a choice of the best entrance variables by some criterion (system of criteria), operating influences (managements) which result system to a desirable (optimum) condition. The decision of a problem of optimization depends on a kind of mathematical model, from target (critarial) function and restrictions on it. The set of methods of optimization (mathematical programming) are developed that are grouped in three - five classes, different by ideology of search of optimum decisions (maximization of function without restrictions, numerical methods, search methods – regular, casual). Optimization methods pass in methods of search of classes of admissible decisions.

10) *Forecasting problems, a scientific prediction*. Forecasting by existing definition is a process of a prediction, a prediction of tendencies and prospects of the further development of those or other objects and their future

condition on the basis of knowledge of regularities of their development in the past and now. Forecasting distinguish from a scientific prediction, it solves narrower practical problems, rather than a scientific prediction. One of advantages of cognitive modeling is the possibility of formalization of processes of a scientific prediction.

11) *Problems of the theory of accidents (catastrophes)*. "Accident" occurs when a spasmodic change of target parameters at continuous change of inputs arises. Position of balanced conditions of a system depends on properties of behavior (dynamics) of a system. Therefore it is necessary to understand, whether and how dynamic properties will change at little changes of system. Studying of this problem has an important practical orientation for displacement of position of balance can lead to essential qualitative changes of behavior of system. One of tools of research of this problem is the *theory of catastrophes*.

12) *Adaptation problems*. The adaptability characterizes ability of system to perceive external influences (expected, unexpected) without irreversible catastrophic changes in its’ behavior. In a sense *the adaptability is a measure of viability*, *survival rate of a system*. The concept of *an adaptability* is closely connected with concept of «attraction area» and with displacement of these areas under the influence of artificial or natural indignations. If these indignations translate system into the area of a catastrophic condition, so the system doesn't possess features of an adaptability in relation to the given class of indignations. Research of feature of an adaptability in mathematical terms demands definition of concepts of "admissible influences», "survival rate", etc.

13) *Self-organization problems*. For definition of concept "self-organization" it is necessary to consider concepts the *open* and *closed* systems. The open system (by definition L. Fon of Bertalanfi) - is the system, capable to exchange in weight, energy, and information with environment. The closed (selfcontained) system is deprived of these abilities. Nowadays open system is understood also as a system which possesses (A.A.Bogdanov's) *active elements*. For example, the organizational systems have active elements such as a person. For open systems the characteristic features are that the system purposes formed inside the system, instead of those ones that are set from the outside, as in the closed systems. In open systems the regularity of self-organizing is shown. *The regularity of self-organizing* - is an ability of system to resist the entropic tendencies, ability to adapt for changing conditions, changing if it is necessary its’ structure, changing the purposes. The concept of self-organizing is connected with concept of adaptivity (adaptability). It was entered by J.Z.Tsypkin at modeling negentropic tendencies in technical systems and has developed the theory of adaptive systems. Further the term of "adaptability" has been transferred on organizational systems, but the term *self-organization* has appeared to be more substantial, then *organization increasing*. To research the regularity of self-organizing the big contribution was brought by I.Prigozhin who has begun *synergetrics*. For technical systems the self-organizing theory is developed by A.G.Ivahnenko.

14) *Problems of the analysis of sensitivity*. Sensitivity shows ability of a system to react to indignations caused by: structure changes, changes of character and force of communication between system blocks, to change of size and time of receipt of a signal. There is one more concept connected with sensitivity -*it is a sensitivity of decisions*. The matter is that parameters of models can't be measured absolutely precisely and their number also can’t be precise. Besides, they can change in actual practice under the influence of the latent factors.

15) *Decision-making Problems*. Decision-making problems can be considered from two positions: as problems of acceptance of administrative and organizational decisions, and as the problems connected with modeling of systems and decision-making on the basis of modeling. Decision-making rules depend on conditions of uncertainty of functioning of the big system, from degree of knowledge of the person, making the decision. In a case when uncertainty is generated by behavior of environment, it is possible to use likelihood models of

problems of decision-making [Gorelova, Svecharnik, 1972], [Gorelova, Brawlers, 2007]- so-called «games with the nature». In case of conflict situations when decision-making in the conditions of conscious counteractions of any other system is considered, models of the theory of games ([Neumann, Morgenshtern, 1970], [Gorelova G.V, Gorelova I. S., 2007] are applicable.

In concrete system research the decision of all above-named problems isn't obligatory, but their complex represents itself as a complete research. As the decision of one problem often is the basis for the decision of the following one, and some of problems can't be solved without one another (a set of others).

4. The scheme of interconnected methods of cognitive methodology

At the present moment cognitive methodology (fig. 1) represents itself a system of models, methods, information technology for research of the big system (Gorelova, etc. (2005) – (2007), (2009), (2010)) which allows to solve interconnectively the primary goals of the system analysis that is necessary for an all-round substantiation of offered decisions on a desirable way of development of a system. There are: methods of formalization of the purposes; methods and models of the economic-mathematical and sociological analysis; methods of gathering and preprocessing of an actual material about social and economic system and environment; methods of cognitive structurizations. Methods are applied stage by stage and allow to formalize knowledges of experts in concrete subject area.

Conclusion

So, the decision of the system problems named above – is the means of more and more deep knowledge of properties of difficult system. There can be the question – what for are so much actions? Whether is easier ….? But: it is obvious that without model of difficult system (cognitive, in this case) and its analysis not only it’s difficult, but more often it’s impossible to understand, predict, develop and make decisions about the adaptation to system or management of it. In the course of research the chain of doubts is born: whether system and model displaying it "are correct"? What are the properties of structure and behavior of system? Whether the system is steady? Whether accident threatens? Can the system has properties of self-organizing, adaptation and is it necessary to do nothing? How much the system is sensitive to influences (to wrong decisions including)? Etc. – on a circle of the decision of system problems.

And these problems are desirable for solving in interconnection. Therefore for each of them there are separately developed methods that can be used in uniform system. These reasons have formed a basis for construction of cognitive methodology of research of the big systems and system of PM KM software supporting it. Thus, integration of possibilities of cognitive technologies with other informational technologies opens unique possibility within the limits of a uniform programme-analytical complex to spend strategic planning and operative reaction, to combine the fundamental and technical analysis of complex system.

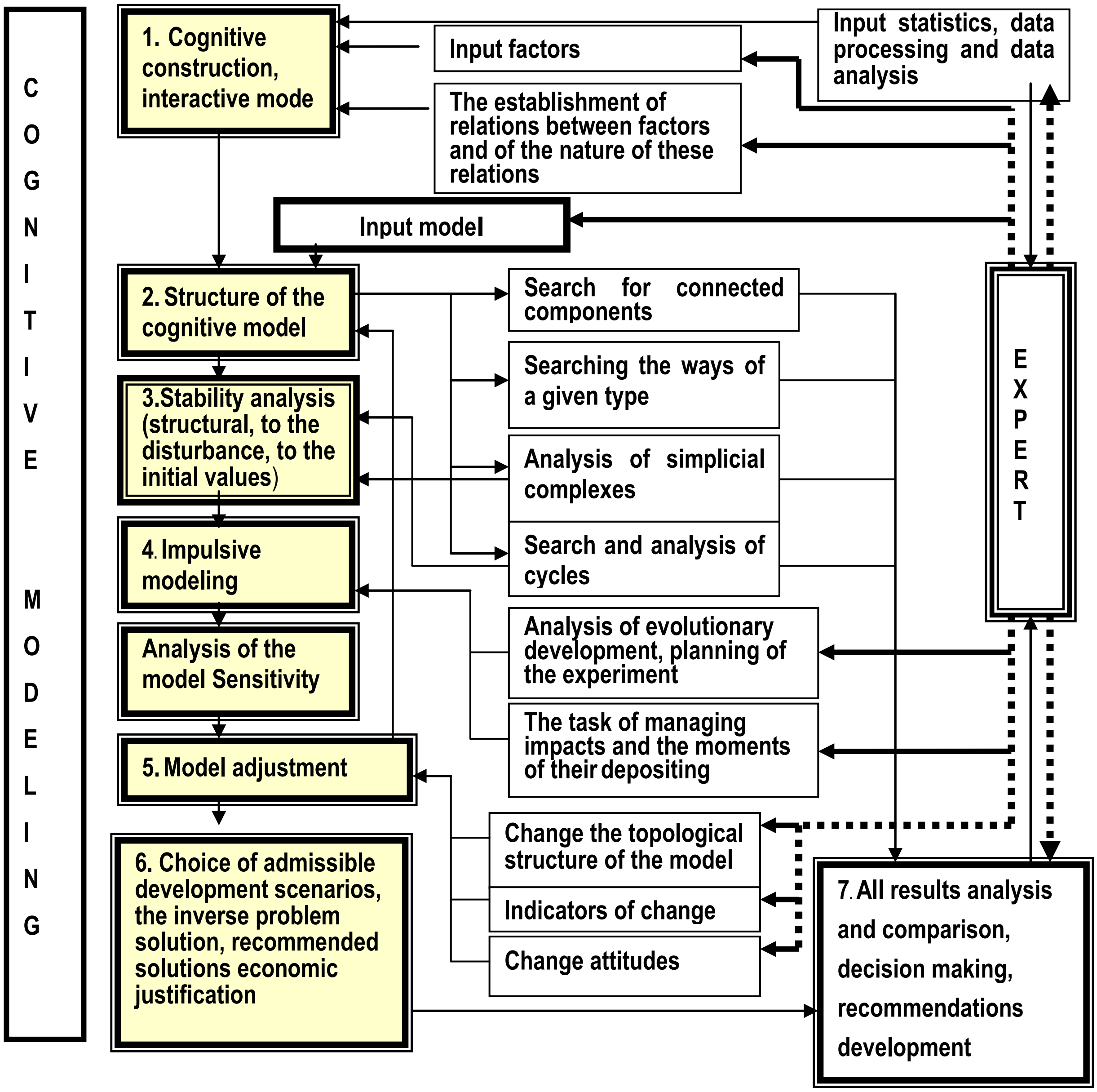

Fig. 1. The scheme of cognitive methodology, interrelation and sequence of application of methods

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