The problem of convergence of intelligent systems and their submergence in information systems with a cognitive decision-making component

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***Abstract*—In this paper the problems of convergence or synergy of knowledge in intelligent systems of one subject area, implemented on different approaches, are considered. The basis is the addition and synonymy of signs (terms) in the knowledge metabases. A version of the work of an information system user with various intelligent decision-making support systems using synonymous concepts is presented. It is proposed to use 2, 3-simplexes to make and justify a decision for converged intelligent systems, and in the dynamics of changes -- 2-simplex prism.**

***Keywords*—convergence of intelligent systems, computer-assisted intelligence design, knowledge metabase, synonym base, semantic interoperability, cognitive component**

> *«Harmony, or rather, "complementarity", manifests itself only in general...»*
>
> — Henri Bergson [1]

> *«Assimilate the method of considering all things in their constant transition into each other»*
>
> — Mark Aurelius [2]

I. Introduction

The structure of an intelligent system includes a knowledge base, a decision inference mechanism, and an intelligent interface [3]. Intelligent systems (IntS) are divided into a number of types and are based on various principles of extraction (acquisition) and analysis of knowledge.

The first in time of occurrence was the class of expert systems (ES), presented on the basis of knowledge and assessments of experts.

Another class of intelligent systems, which can be called traditional, is based on revealing knowledge from literature data, documents or (in medicine) from arrays of health records. The knowledge revealed in IntS, as well as in ES, is presented in the form of a rule base. In some cases, the knowledge of highly qualified experts is also included in the knowledge base of the intelligent system [4].

A special class is made up of JSM-IntS [5], the solver of which is implemented on the basis of intelligent qualitative analysis of data, which is arguments and counterarguments for hypotheses accepting, followed by the presentation of selected signs as elements for explanation. The JSM-method for automated generating of hypotheses presents formalized heuristics for establishing the causes (presence or absence) of the effects studied, presented in open (updated) databases of structured facts.

Case-based reasoning [6] contains situations or precedents, and the solution comes down to abduction from particular to particular (to search by analogy).

L. Zade proposed to call hybrid those systems in which fuzzy logic is combined with neurocomputational, genetic algoritms and probabilistic computational [7]. In the future, other combinations began to be used.

The totality of concepts in intelligent systems of various types can correspond to judgments and hypotheses implemented on various approaches. In the future, it is necessary to search for a single solution to represent knowledge at various stages of intelligent systems building, which will allow the user to receive a number of hypotheses from different IntS in one session with a single software product for entry. However, given that the full integration of various intelligent systems seems theoretically impossible, we consider the concept of convergence, which is accepted in foreign literature to be considered as sinergy.

II. Integration or convergence of intelligent systems?

We introduce the concept of convergence (from Lat. Convergere – to approach, converge) as a way of convergence on the basis of common approaches to building the same type of modules with an agreed standardization of certain data, according to the option proposed for information systems (IS) [8].

The movement in the direction of convergence can be based on the principle of "weak integration" according to the principle of corporate information systems, which implies a certain degree of redundancy with a simultaneous margin of system flexibility [9]. In a broad sense, convergence refers to the interpenetration of several sciences and scientific fields.

On the convergence of scientific trends, some intelligent recognition systems are based. Among them, one can single out the theory of discrete automata, test pattern recognition, logical-combinatorial, logical-probabilistic algorithms, soft computing, cognitive graphics tools (CGT), dividing systems, optimization of the selection of fault-tolerant diagnostic tests [4], [10], [11].

We assume that the greater the interpenetration, the higher the degree of convergence.

In studies at the intersection of sciences and scientific fields, the use of convergence allows, through interpenetration, to obtain a synergistic effect in solving problems of analyzing data and knowledge, identifying various patterns, making and substantiating decisions, including using cognitive means.

The convergence of knowledge in IntS, based on various methods of artificial intelligence, should be considered at the stages of its creation: extracting knowledge from various sources and presenting it in a single structured form, forming knowledge bases (rule bases) and inference mechanisms, explaining proposed hypotheses, implementing interfaces, as well as fact bases. Let's consider some aspects of the example of medical applications. In this regard, it should be noted that the signs observed in patients are data, but for the doctor, relevant indicators correspond to knowledge about diseases and serve as arguments for putting forward diagnostic or prognostic hypotheses.

The ontology of taxonomic terms may be a structurally formalized representation in the model Resource Description Framework (Resource Description Framework – RDF), which is represented in the form of a triplet "subject -– predicate -– object" (for example, in the clinical version of the medical description "skin – has color – pale"). Many RDF-statements form a directed graph in which the vertices are subjects and objects, and the edges represent relationships. RDF is an abstract data model, that is, it describes the structure, methods of processing and interpreting data [12]. Based on RDF, for example, the Metagenome and Microbes Environmental Ontology was built [13], [14].

The complex of knowledge sub-bases of intelligent systems of the same subject area complementing each other, connected by certain relationships, will be called the metabase of knowledge. In such converging systems controlled by a body of knowledge, the exchange of information is possible through a common "memory" based on a unified representation of the information being processed through common terms. A complex of interrelated sub-bases of knowledge can carry out real interaction only under the condition of semantic interoperability.

III. The problem of semantic interoperability

The concept of compatibility of software systems should serve as the basis for fundamental communication, integration and effective sharing of knowledge and data by systems, organizations and users. In particular, semantic compatibility is a way of a common understanding of context and meaning, which ensures the correct interpretation of the message received, in particular the disease of a particular person, which is based on unambiguously understood factual data. In this regard, we can talk about a critical approach to the concept of semantic compatibility for communication and exchange of medical data.

Particular emphasis is needed in relation to clinical terminology [15]. An effective solution to this issue is possible with a coordinated exchange of information between intelligent systems on the basis of common classifiers and formats of knowledge about various indicators characterizing the manifestations of diseases at different stages of their progression. But this requires appropriate development of the composition of semantic information, its coding and rules for the exchange of knowledge.

The practical implementation of semantic compatibility requires vocabularies, taxonomies, ontologies and a description of relationships. That is, a semantic model of a subject domain can be implemented on ontologies integrated into a semantic network of a subject domain with their properties and relations between objects. Ontologies can perform an integrating function, providing a common semantic basis and a single platform [16]. On this basis, it is possible to represent knowledge, the subsequent combination of individual modules of various intelligent systems.

To each concept characterized by the presence of synonyms, ontologies of synonymous series must be added. Using a block of synonyms, primary input terms will be replaced with synonymous concepts presented in knowledge bases and case studies of various systems of the subject area. Thus, the semantic core of the subject domain metasystem should ensure the interoperability of intelligent systems built on various principles using classifiers, including standards for coding and exchange of characteristic features with the semantic "core" of the subject area (Fig. 1).

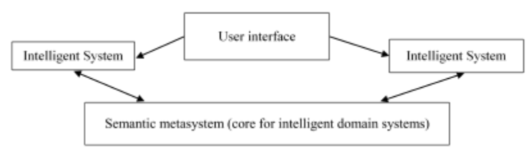

Figure 1. The semantic exchange scheme for the unification of terms

In medicine, these are clinical health indicators, for example, the Systematized Nomenclature of Medicine – Clinical Terms [17] or the search for hierarchical relationships between multiple terms that support multiple parents in a single term, for which semantic networks and trees were used [18].

The knowledge base should provide the possibility of "understanding" of synonyms as a result of appropriate labeling of synonymous concepts and the exchange of knowledge with the base or module of synonyms in the process of replenishment under the supervision of experts when a new concept is discovered (Fig. 2). New concepts may be included in the metabase or rejected. Meta-descriptions of domain objects in the framework of the ontological model make it possible to take into account their semantic meaning [19]. In healthcare, syntax for adapting knowledge has been developed for specific tasks. Arden Syntax for Medical Logic Module was originally developed to share health knowledge [20].

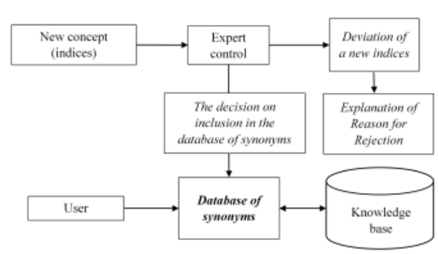

Figure 2. Refillable base synonymous concepts

For users of systems, unlike experts, it is necessary to provide access to the database of synonyms as read.

IV. Convergence at the stages of building intelligent systems

Convergence is impossible without the use of homogeneous classifiers, including, if necessary, synonymous concepts. These classifiers should be applied at every stage of building an intelligent system for a specific subject area (possibly for a separate problem area) – in the process of knowledge extraction, structuring of knowledge (including visual structuring), development of an explanation module and user interface.

Consider the option of building a converged IntS user interface. It is possible to enter data terminologically familiar by name for a particular user, followed by checking for the presence of synonyms and replacing it with a name that is adopted by agreement of experts in the subject domain. For this, there must be a base (module, block) of synonymous concepts of the subject domain, shown in Fig. 2.

When forming an explanation of hypotheses put forward by the system, it is also necessary to use a base of synonymous concepts.

The convergence of intelligent systems, implemented on a semantic network that combines the knowledge bases of individual intelligent systems through key concepts of subject domains, should generally correspond to the proposed concept of an OSTIS system [21], that is, all stored information should be structured on the basis of a thesaurus (multi-level classifier), which should serve as the basis for the component construction of system interfaces and should ensure the simplification and acceleration of their correction, if necessary.

V. Embedding of intelligent support in information systems

In the process of a user working with an information system, a need arises to support various solutions, for which more than one intelligent system can be used. The problem arises of knowledge-driven IS [22] while ensuring the semantic interoperability discussed above. Consider this with healthcare. In medicine, the idea of "embedding" decision-making support systems in electronic medical records arose in the last century. Its implementation can be represented by the example of the versatile American system Siegfried (Fig. 3) [23]. This system allows you to take into account 1700 guidelines for a variety of nosologies and give reasonable recommendations for the treatment of patients. In the 4th generation of improved databases of medical information systems (MIS), computer-assisted software design [24], although not intelligent, was constructed. Accordingly, at this stage there were still no solutions necessary to ensure user dialogue with the embedded system.

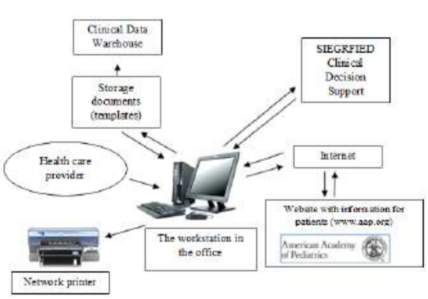

Figure 3. Siegfried: Medical system for Interactive Electronic Guidelines

At the same time, the task is to implement the necessary functional properties and characteristics that meet the requirements of doctors in the decision-making support modules. With this in mind, within the framework of the INTERIS information system [25], a specialized module for assessing the state of central hemodynamics in cancer patients was created. Based on six hemodynamic parameters, 12 syndromes were identified that reflect the state of blood circulation and the severity of hemodynamic disturbances in operated patients with oncological pathology. The results of the measured parameters are recorded in the MIS database, which provides a link between it and the intelligent decision-making support system. A resuscitator uses the information obtained when making decisions in the process of forming medical prescriptions. The DOCA+ clinical information system [26] provides an analysis of the fundamentally important functions of the body by signaling violations of the norm limits set for various indicators -— heart rate, blood pressure, etc., which allows you to issue warnings about potential risk for patients. From modern perspectives, the most efficient use of such functions in the treatment process is possible when moving to intelligent systems and using the method of situational management [27], which is especially necessary for dynamic intelligent systems. Similar situational management solutions can be applied in various fields.

The medical informatics manual [28] emphasizes the need to make greater use of active computer systems that generate various clinical signals or treatment recommendations. It is also proposed to use artificial intelligence as a cognitive assistant to a doctor, for example, to search for specific patterns in clinical data that indicate important changes in the patient's condition.

VI. Interactive data exchange

The concept of "MIS-Mentor" was introduced in the five-level MIS paradigm, which implies an interactive dialogue between the intelligent module and the user to request signs that are missing for decision-making. The refusal to obtain additional data in the dialogue, as some authors believe [29], should be recognized as incorrect, since it is impossible to imagine that the doctor will introduce all the data necessary for the formation of hypotheses. Accordingly, the decision on an incomplete data set will lead to a decrease in the efficiency of the hypotheses proposed by the intelligent system. Previously, it was shown that IntS can be more confident in the diagnosis when receiving information about the patient's manifestations of the disease in accordance with the recommendations on additional studies important for decision-making [30].

In the information system may be incorporated ("immersed") series of intelligent systems to provide the solution of various problems. In this case, the problem of their compatibility with each other arises. It is necessary to solve the problem of data and message exchange structure. The structure of the terminological representation of domain knowledge should be unified and replenished, otherwise no convergence is possible. O.I. Larichev et al. [31] drew attention to the need at any time to return to the stage of structuring and supplement the set of criteria.

As for the convergence of MIS [8], it seems appropriate to switch to a modular structuring of knowledge in artificial intelligence systems, which will simplify and accelerate restructuring when new or adjusted knowledge is included in the thesaurus. Previously, the hierarchy of the structure of concepts was considered in the data field using the so-called multidimensional tubes, and the decomposition of the structure was presented as a meaningful analysis by its specialist [32]. This work was written to solve problems by computational methods of pattern recognition, but at a critical stage in the creation of knowledge-based systems, and included the evaluation of data by specialists in the subject area. However, the modularity of knowledge at the stage of its extraction and structuring has not yet been adequately reflected in the construction of intelligent systems. And without solving this issue, it is impossible for the user to switch in the process of working from one intelligent decision-making support system to another. The transition to the modular structure of classifiers will be the basis for the ability to interact with their individual sections-modules. At the same time, full user support should include various aspects of process control for which separate knowledge bases can be used.

It should be emphasized once again that when switching to the inclusion ("immersion") of intelligent systems in information systems, the main problem is on-line data exchange in those cases when there is not enough data available in the information system to make a decision and they must be additionally requested or clarified from user. Off-line mode is not acceptable for many situations.

VII. The cognitive component of decision-making

A large number of publications by the authors of this article are devoted to the cognitive component of decision-making. The Cognitive Graphics Tool (CGT) visually mapping a complex object, phenomenon or process on a computer screen, allowing users to formulate a new solution, idea or hypothesis based on visual elements. Cognitive graphic tools were developed as one of the areas of Artificial Intelligence in the 80s of the 20th century in the works of D. A. Pospelov and A. A. Zenkin. For the first time, A. E. Yankovskaya proposed the CGT n-simplex ($n = 2$ is an equilateral triangle, $n = 3$ is a regular tetrahedron) and developed in publications [4], [33], [34]. Initially, 2, 3 – simplices were also used to create dynamic intelligent systems, but in 2015 A. E. Yankovskaya and A. V. Yamshanov proposed to use a 2-simplex prism for various problem areas to create dynamic intelligent systems [34].

A 2-simplex prism is a triangular prism with identical equilateral triangles (2-simplexes) at its bases. The height of the 2-simplex prism [34] in dynamic intelligent systems corresponds to the considered time interval of the dynamic process. It is divided into several time intervals. The number of time intervals corresponds to the number of diagnostic or prognostic decisions. The distance between two adjacent 2-simplexes is proportional to the time interval between them (Fig. 4).

Under the direction of A. E. Yankovskaya user-oriented graphical, including cognitive, tools were developed, designed to visualize information structures, revealed regularities, make and substantiate decision-making both for specific problem areas (having a mapping in ordinary reality (naturalistic CGT) [4], [33], and for invariant to problem areas, that is, not mapping in ordinary reality [4], [33], [34].

Unfortunately, the scope of this article does not allow to consider even a part of the created cognitive graphics tools (CGT) to be stated. Here are just some of them devoted to the cognitive component of decision-making and the substantiation for decision-making [4], [33], [34]. The publication [4] presents the cognitive tool n-simplex ($n = 2$, $n = 3$), which allows you to save the sum of the distances to the faces and the relationship between the distances. This cognitive graphics tools of decision-making and substantiation of decision-making does not have a mapping in ordinary reality and, since it is invariant to problem areas, it is oriented to any problem areas, which is especially important for converging intelligent systems. The publication [33] presents CGT for specific problem areas that has a mapping in ordinary reality (naturalistic CGT). The cognitive way of mapping in ordinary reality is based on the use of images of real objects. In the publication [34], for synergistic IntS, a cognitive tool 2-simplex prism is presented, which is invariant to problem areas and implemented for medical and other problem areas that take into account changes in time (in the dynamics of the pathological process), and for geoinformation systems that take into account changes in space (for example, the distance on the map).

For the differential diagnosis of various diseases, the 3-simplex cognitive tool was used [4], [10], [11], which visualizes the degree of disease manifestation [33] (the presence of one or more of 4 diseases with an indication of the accuracy of each decision).

The cognitive tool "2-simplex prism" can be considered as the cognitive component of the convertible dynamic IntS (online dynamics options are not considered, the dynamics is considered as changes over time).

Distance from the basis of the 2-simplex prism to the i-th 2-simplex h'_i, representing the object under study at a given point in time, is calculated by the following formula:

$$h'_i = H' \cdot \frac{T_i - T_{min}}{T_{max} - T_{min}}$$

where H' is the height of the 2-simplex prism preassigned by a user and corresponded to the study duration, T_i is the moment of the i-th fixation of the parameters of the object under study, T_{min} is the moment of the first fixation of the parameters of object under study, T_{max} – the moment of the last fixation of the parameters of the object under study.

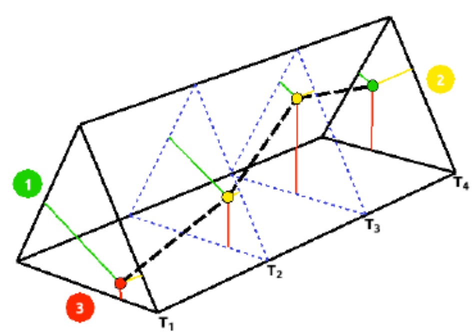

Figure 4. Example of 2-simplex prism usage for visualization of dynamical processes

Since the 2-simplex prism is based on the use of 2-simplex, all the properties of representing objects on a 2-simplex are also valid for a 2-simplex prism.

2-simplex prism allows you to model and map dynamic processes.

Examples of the use of a 2-simplex prism in synergistic dynamic IntS are presented in medicine for the differential diagnosis of various diseases [33], [34] and in geoinformation systems [34].

VIII. Conclusion

In the process of development of convergence (synergy) of intelligent systems and their integration with information systems, new opportunities are opened up for users in terms of working simultaneously in IS while providing broad support for decision-making in an interactive process with systems based on domain knowledge. But for this need good solutions for hooking together software components from various developers, network communication technologies provide standards that can be leveraged for low-level hookup and semantic integration [35]. The problems of interoperability at the semantic level are discussed above with respect to the construction of interfaces, knowledge bases, and explanation blocks. The cognitive graphics tool proposed for use in converged intelligent systems are based on two approaches: those that have and do not have a mapping in ordinary reality. Cognitive graphics tool are applicable for modeling various processes in problem and interdisciplinary fields, such as genetics, psychology, sociology, ecology, geology, construction, radio electronics, economics and others. For the decision-making and substantiation converged intelligent systems cognitive graphics tools 2, 3-simplexes have been developed, and for dynamic – 2-simplex prisms. It is shown that the use of cognitive graphics tool allows you to make and justify decisions in IntS both in statics and in dynamics.

The integration of convertible intelligent ostis-systems for decision-making support into information systems and their implementation in the format of cloud technologies will significantly expand the possibilities of using large systems that are not available for financial reasons to individual institutions/firms.

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Проблема конвергенции интеллектуальных систем и погружения их в информационные системы с когнитивной компонентой принятия решения

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В настоящей работе рассматриваются проблемы конвергенции или синергии знаний в интеллектуальных системах одной предметной области, реализованных на различных подходах. В основу положены дополнение и синонимия признаков (терминов) в метабазах знаний. Представлен вариант работы пользователя информационной системы с различными интеллектуальными системами поддержки решений в рамках использования синонимичных понятий. Для принятия и обоснования принятия решения для конвергируемых интеллектуальных систем предлагается использовать 2, 3-симплексы, а в динамике изменений — 2-симплекс призму (2-simplex prism).

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