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Research Article

Systems Science: Digitalization of Transdisciplinary Research

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ABSTRACT

The conceptual foundations of transdisciplinary researches with the use of methods and means of artificial intelligence, including ontological engineering, have been developed. The stages of formation of the theory of transdisciplinarity are defined, in which the processes of building the categorical level of concepts and integration of subject knowledge, the formation of clusters of convergence of subject disciplines, the scientific picture of the world and the corresponding global network of transdisciplinary knowledge take a special place. In this case, a special role belongs to informatics as a system-forming branch of knowledge. The development of the NBIC-cluster of convergence opens wide, so far completely not assessed, possibilities of a global knowledge-oriented Internet, but with it also the whole of modern civilization. Obviously, this development will follow first the path of creation of the applied distributed systems in specific subject areas (Internet of Things, Smart systems in telemedicine, environmental monitoring, information support of goods and services, energy systems, utilities, etc.). Grid-, Block-chain-technologies and Cloud-computing, as well as virtual organizations, structures and services will occupy the central place in them.

1. Introduction

In the modern scientific picture of the world (SPW), based on the ideas of the general concept of evolution, self-organization, co-evolution, nonlinearity, it is assumed that the subject understood as a society, enters the system it cognizes as an active component of this process-system [1], [2].

There was a philosophical concept called the transhumanism, which is exploring the possibilities and consequences of achievements of science and technology, the dangers and the benefits of using them. In opposition to transhumanism, the ideas of posthumanism are represented, the central thesis of which is the acceptance of *Man*, *Society* and *Nature* as three jointly evolving systems [3].

Techno-science have become a force capable of fundamentally changing the nature of man and his life activity. Nowadays, in connection with convergent technologies, the question has arisen, to what extent is humankind ready to go in these transformations when they concern the person himself? This question involves not only the sphere of self-knowledge and self-development, but also self-preservation. Below the ontological representation of the noosphere is given, in which, inter alia, issues of the development of human society are touched upon.

It was necessary to expand the scientific worldview what requires science more deeply and intensively penetrating into the essence of the laws of nature and society, than it was possible to do with the help of disciplinary and interdisciplinary approaches. J. Piaget believed that “after the stage of interdisciplinary research, one should expect a higher stage — transdisciplinary, which will not be limited to interdisciplinary relations, but will place these relations within the global system, without strict boundaries among disciplines. Transdisciplinarity should be considered as a new field of knowledge, different from multidisciplinarity and

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interdisciplinarity" [4]. Historical aspects of the formation of transdisciplinary research are considered in [5].

The purpose of this publication is to develop a conceptual framework for the digitalization of transdisciplinary scientific researches.

2. Brief Description of Types of Scientific Researches

In terms of the classification of scientific approaches, it is useful to choose such criterion as the degree of completeness of knowledge of the surrounding world. Then all the approaches can be reduced to four main types: disciplinary, interdisciplinary (ID), multidisciplinary and transdisciplinary (TD) approaches.

Interdisciplinarity is understood as the integration of scientific areas through mutual penetration of common concepts. The term "multidisciplinarity" means such research, when an object, process or phenomenon is studied simultaneously in different aspects by several disciplines at once.

In this paper, these terms are understood depending on the "distribution" of concepts and scientific disciplines with respect to the ontological levels of hierarchy, which implies different patterns of their interaction. Such distribution is essential when considering the methodology of the TD interaction, system integration of subject disciplines and formation of the "convergence clusters" in implementation of transdisciplinary projects and their information and technology support.

Such notions as Noosphere, Object, Process, System, Information, Nature, Society, Man, Subject Branch, Science, Scientific Activity, Scientific Picture of the World, Engineering, Technology, etc. refer to the category level. Such concepts as Philosophy, Physics, Mathematics, Biology, Chemistry, Medicine, Humanities and Social Sciences, Informatics, Nanotechnologies, etc. refer to the level of domains of scientific disciplines. Many scientific disciplines which are directions, sections

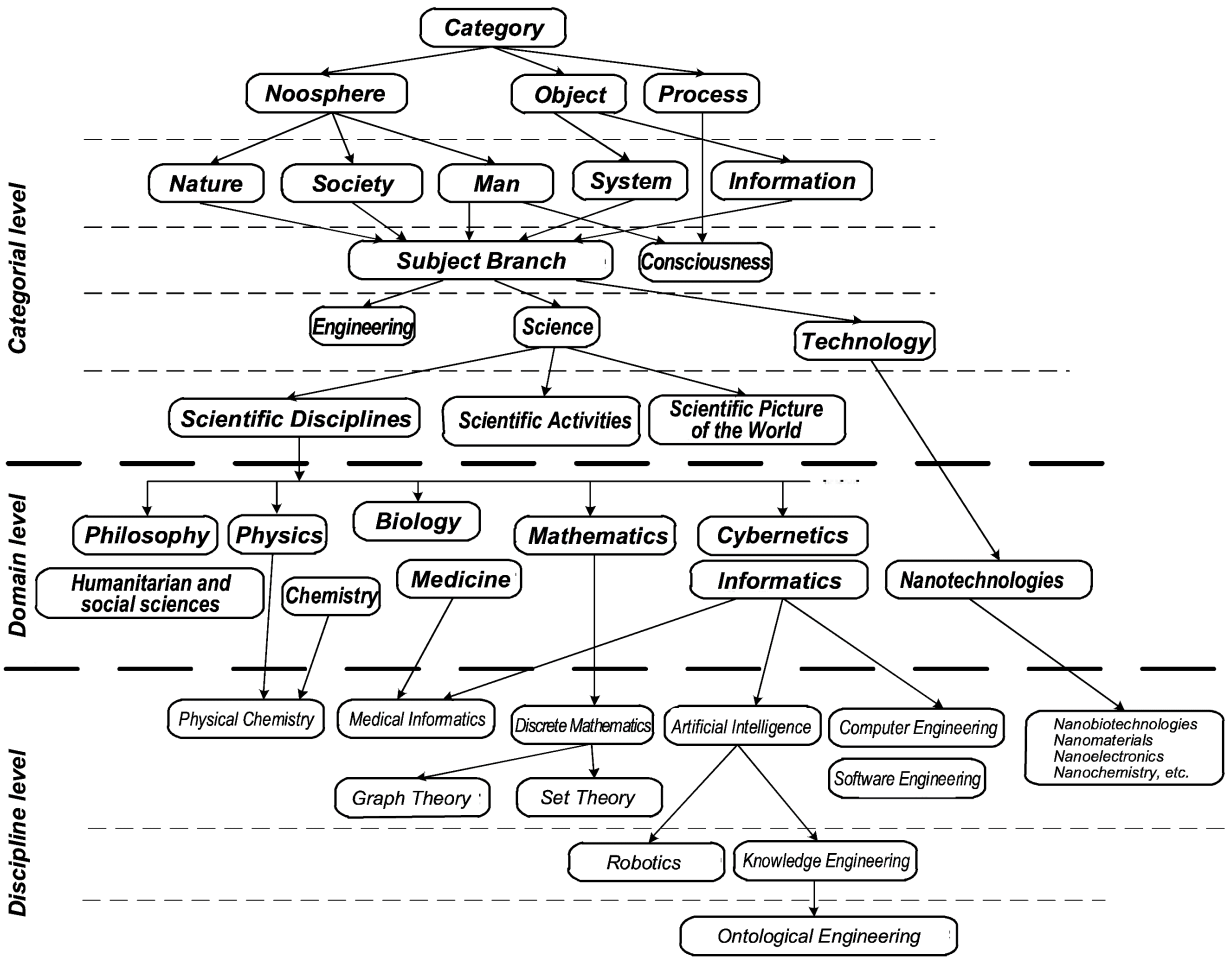

Fig. 1. The analysis times of numerical integrations

and sub-domains of domains, refer to the level of scientific disciplines.

Aforesaid is explained by the scheme presented in Fig. 1.

Disciplinarity allows science to develop progressively within subject directions, and a disciplinary approach divides the surrounding world into separate subject areas. If solving a task or problem goes beyond the scope of disciplinary approaches, it is commonly believed that it is "at the intersection of scientific disciplines". In the process of progressive development of the disciplinary approach, an opposition occurs, which conditions on the one hand, the accumulation of disciplinary knowledge, and on the other, is the establishment of a natural limit to the fullness of knowledge of the surrounding world. The way out of this situation is indicated by the following thesis: "If it is impossible to go beyond the disciplinary direction, then the scope of disciplinary methodology can be extended" [6]. In turn, the expansion of the field of application of disciplinary methodology has led to the emergence of interdisciplinary and multidisciplinary scientific approaches, which made up the following levels of classification of scientific approaches. The process of their development has led to the fact that the metaphor "the junction of disciplines" gradually acquired the form of interdisciplinary and multidisciplinary directions, each of which has its own characteristics of solving tasks.

Interdisciplinarity involves the integration of several scientific disciplines. One of them plays a leading role, and the results of ID-research are always interpreted in terms of leading discipline. The peculiarity of the ID-approach is that it allows direct transfer of research methods from one scientific discipline to another. The transfer of methods in this case is due to the discovery of similarities of the studied subject areas. ID approach is intended first of all, to solve specific disciplinary problems in which solving in any particular discipline the conceptual and methodological difficulties arise.

Synergetic paradigm as a section of the ID-approach in the hierarchy of knowledge occupies a special place. On the one hand, it appeals to integrity and integral representation, systematically determining the effects of objects, processes and subjects' interaction, on the other hand, focuses on nonlinearities, instabilities and the appearance of attractors, which ultimately change multi-level organization and system behavior. In both cases, it is expressed by a set of formal models of self-organization and is directed to reproduce the scientific picture of the world, which is especially important during the transition to a transdisciplinary approach to research and implementation of the paradigm of global evolutionism. SPW can be represented as a TD-ontology, which incorporates not only the ontologies of individual disciplines, but also the methods of the latter, including variants of their cross exposure. TD allows one to build a unified TD-methodology of analysis and synthesis, including it in the general scientific picture of the world. In more detail the problems of synergy are considered in [5].

Multidisciplinarity does not imply the transfer of research methods from one discipline to another. All disciplines retain their subject directions.

In a multidisciplinary approach, researchers form a generalized picture of the subject of the research, in relation to which all of its disciplinary pictures appear as its equal in rights parts. The accumulation of results of multidisciplinary research in similar areas of disciplinary knowledge leads to the emergence of new multidisciplinary disciplines, such as physic-chemical biology, ecology, etc. The multidisciplinary approach has found its practical application, in particular, in the work of expert groups.

TD system approach uses the knowledge generated and accumulated by disciplinary, interdisciplinary and multidisciplinary approaches. TD should ensure coordination and integration of disciplinary knowledge on the basis of a single axiomatic approach (the TD general systems). This is how TD was originally imagined by J. Piaget and E. Jantsch [4], [7].

Transdisciplinarity is a research strategy that crosses disciplinary boundaries and develops holistic (priority consideration of the whole in relation to its parts) vision. TD in the narrow sense means integration of various forms and methods of research, including special techniques of scientific knowledge, for solving scientific problems. TD to wide extent means the unity of knowledge beyond specific disciplines.

Let us note the changes in the structure of science, due to the transformation of a disciplinary organized science in TD research:

- highlighting the following signs of the post-nonclassical stage: a change in the nature of scientific activity, due to a revolution in the means of obtaining and storage of knowledge (computerization of science, fusion of science with industrial production, etc.); increase of the importance of economic and socio-political factors and goals; change of the object of study itself — open self-developing systems ("human-sized" objects, examples of which are biotechnology objects, ecological systems, biosphere, etc.) [5];
- TD-studies, capturing the border zones (demarcation) areas of scientific disciplines, integrate the essential foundations of the latter, forming the so-called convergence clusters, in which a powerful synergistic interaction occurs due

to the interpenetration of paradigms and specific current results of each of the disciplines included in one or another cluster. This interaction reflects the integrity of the real world, being an incentive and at the same time a guarantee of the success of TD research and related practical projects, the non-triviality and significance of their results [8].

3. Transdisciplinarity and Formation of Convergence Clusters

The unity and systemic complexity of the world as an object of scientific research suggests that, along with the process of differentiation, it is advisable to consider the process of integration of scientific disciplines and relevant technologies. After all, it is the fundamental paradigm of the evolutionary theory of academician Vernadsky. The process of integration, which began quite recently, seemingly on a spontaneous (intuitive) basis, is now becoming conscious and obvious. And most importantly, prompted by evolutionary theory, it is aimed at creating a Single Common Knowledge, the essence of which clearly appeals to the construction of a Scientific Picture of the World based on a transdisciplinary concept of the development of science. The first stage of the integration process can be called the clustering stage. The most superficial analysis of the clustering phenomenon shows that it is based on a deep interaction of methods, tools and capabilities of the cluster components, the synthesis of which generates synergistic effects through the integration of the functional properties of these components and opens up broad prospects for creating previously unknown scientific theories, samples of new equipment and technologies. The integration process that has already begun raises many questions, the answers to which will allow us to outline new promising ways of evolution of knowledge and science in general in accordance with Vernadsky's noospheric theory. One of the tasks on this path is to analyze the structure of knowledge at the conceptual level. General knowledge and each of its disciplines can be represented by a total set of concepts-terms that constitute the ontological basis for describing knowledge, formal or informal. Each term has its own generally accepted definition, which is described using lower-level terms (or concepts). A technological multilevel ontological description of both general knowledge and its individual disciplines, sections, theories, etc. has been created, opening up the possibility of formal knowledge representation using a single ontological engineering toolkit, which opens up broad prospects for the development of cognitive technologies and their productive use [2].

Currently, there is a tendency to intensify scientific research both at the intersection of different subject disciplines (interdisciplinary research) and in convergence clusters (transdisciplinary research). To support these studies, important factors are the construction of knowledge-oriented information systems, improvement of research design processes, development of methods and tools for ontological analysis of natural language objects in order to extract knowledge from them, applied aspects of the use of ontologies, meta-ontologies, knowledge integration systems in transdisciplinary convergence clusters [5].

The cluster of NBIC-convergence and intersecting with it LIInK-cluster (L — language, I — information, In – Intelligence, K — knowledge) can serve as a vivid example of technoscience. Informatics brings to these clusters both system-forming, and computer-technological components. The main breakthrough directions in these clusters are: erasing the faces between living and inanimate systems, nanorobotics with its numerous applications, global supercomputer agglomerations with a high level of artificial intelligence. To these should be added the unified distributed TD-knowledge system as a globally-communicative version of a general scientific picture of the world and the next stage of development of the existing Internet and the Semantic Web. In [2], a possible scheme for predicting and targeting the formation of promising convergence clusters is proposed according to the scheme shown in Fig. 2.

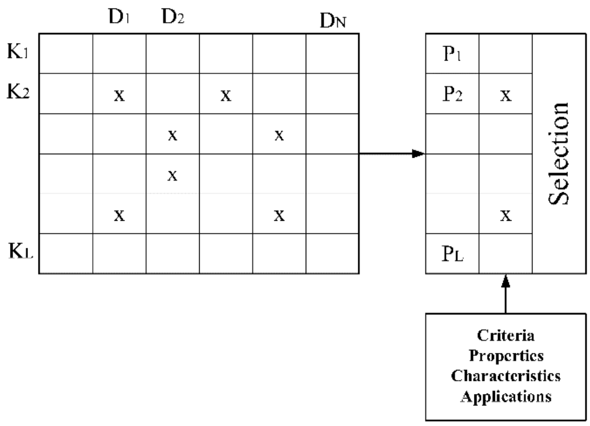

Fig. 2. Approximate scheme of formation of prospective convergence clusters

Here $D_1, D_2, ..., D_L$ – disciplines and their corresponding technologies, $K_1, K_2, ..., K_L$ – convergence clusters, $\{P_i\}, i = 1, 2, ...M < L$ – selection and application of promising clusters.

Fig. 3 presents the scheme of interaction of domain-level concepts in the formation of convergence clusters.

Thus, TD research is a qualitatively new stage in the integration of science and society. For its completion, the scientific community still has much to develop, in particular:

- general scientific picture of the world, including subject disciplines, and the corresponding global network of TD knowledge;
- metatheory and metalanguage of TD;
- the systemology of TD interaction, the figurative conceptual apparatus and models, the possibilities of which would allow, on the one hand, to cover all factors forming a complex problem and affecting it, on the other hand, to identify and take into account the mechanisms by which this effect is carried out;
- the method (or a set of methods) of system research, providing access to all disciplinary information and its analysis, is understandable and available to specialists of any scientific discipline;
- prospective and self-sufficient convergence clusters that make up the core of the sixth technological order;
- the methods of conducting experiments that allow studying the multifactorial effects of objects of knowledge and evaluating their results. Including various information technology tools to increase efficiency and accelerate results [6], [9], [10], [11], [12];
- the ways of posing and solving complex multi-factor problems in science, engineering and technology.

The listed tasks are generalized and, in turn, include a number of subtasks.

3. Transdisciplinarity-noosphere Concept-picture of the World

It is in the transition to a knowledge society and TD-knowledge-oriented technologies the system forming role of informatics is manifested for real. The path to the TD lies through the creation of the system of ID interactions (in the light of the evolution of scientific theories) as an independent branch of knowledge. Moreover, informatics, in addition to a clear mathematical basis, also grasps technologies of posing and solving complex scientific-engineering problems.

Thus, the essence of the TD approach to the study of complex scientific and technical problems consists in effectively ensuring the dual unity of the concepts of deepening specific knowledge in the subject area, on the one hand, and expanding the coverage of the problem, based on the reality of the unity of the world, and recreate a holistic SPW on the other.

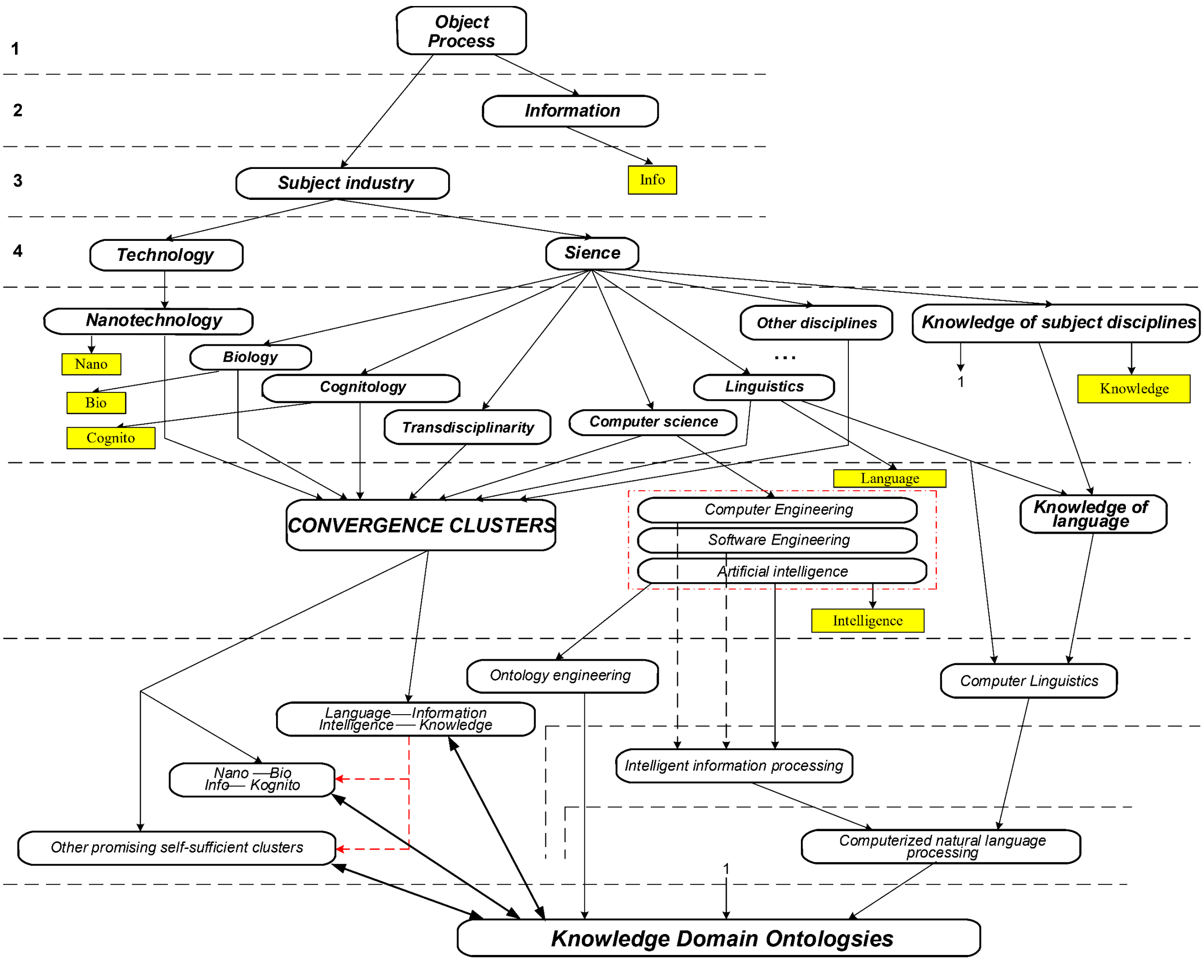

Fig. 3. Scheme of interaction of domain level concepts at formation of convergence clusters

The terms: noospherogenesis, transdisciplinarity, ontology-driven systems, virtual paradigm, information and cognitive support for scientific research, personalized knowledge bases, smart projects, Internet things clearly outline, first of all, the subject area of informatics and information technologies of the XXI century, focused directly on the stage of human development, based on knowledge economy. In fact, the process of noospherogenesis, according to V.I. Vernadsky, touches on the deeper aspects of interaction in the "Man-Nature" system. It appeals to scientific thought and, consequently, to the cognitive resources of the human mind and SPW, the construction of which is impossible without the TD approach to science and human civilization as a whole [8]. Fig. 4 shows a variant of the categorial level of the noosphere and possible prospects for the development of human society.

The Fig. 4 shows the main concepts of the noospheric paradigm, they are dominated by the triad "knowledge-oriented concept collective mind sustainable development of society".

TD-studies allow one to understand the complexity of the problems being solved, to take into account the diversity of ideas about the life world and the problems posed, to link abstract and concrete knowledge with the use of the "ontological engineering" and global network of TD knowledge.

Methodologically TD-studies include a number of main stages:

1. analysis of the problem, its identification and structuring;

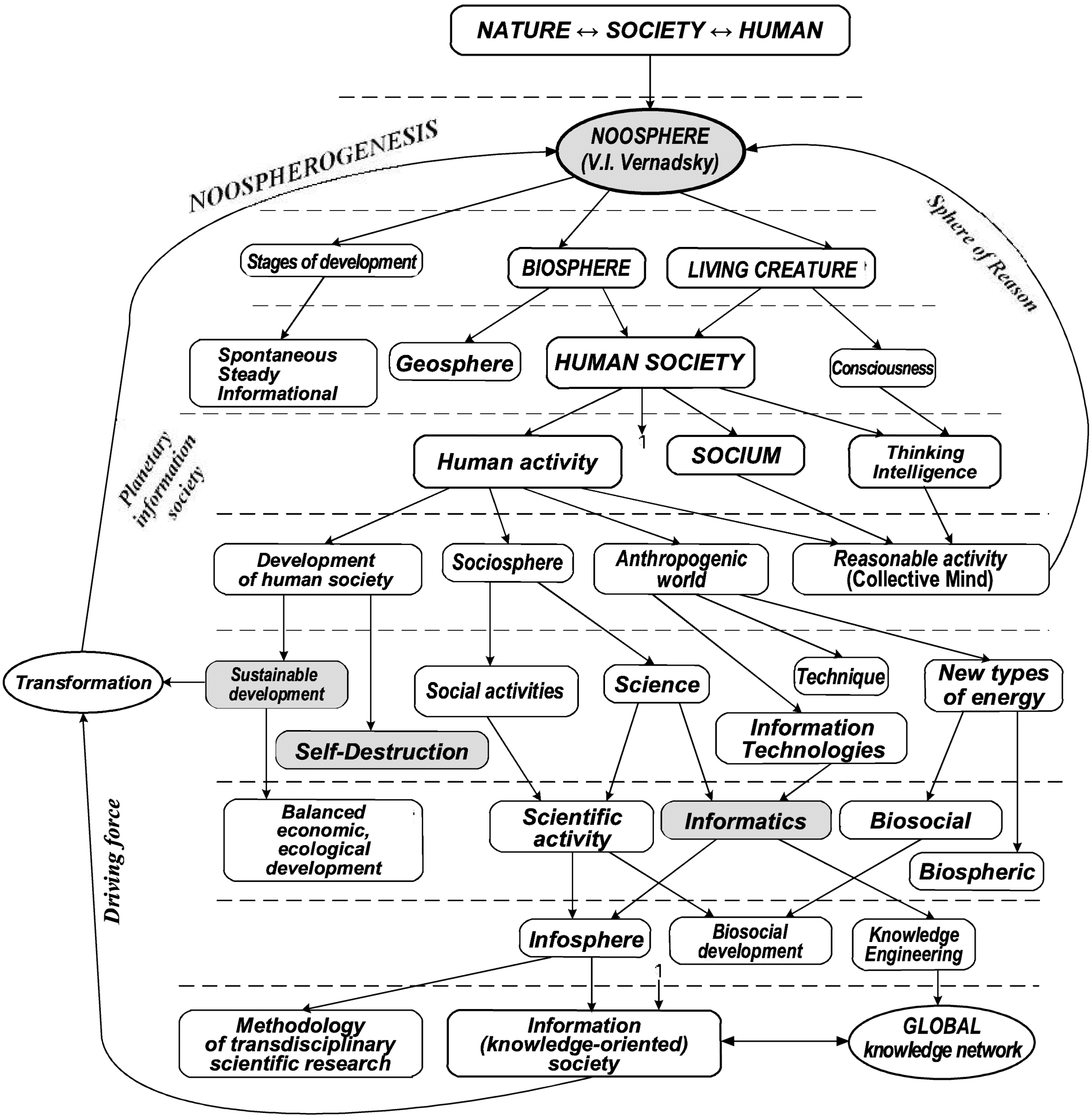

Fig. 4. Scheme of the Noosphere categorical level

2. the development of the missing theoretical material necessary for problem solving;
3. the construction of clusters of convergence of subject areas;
4. choice of a language (or development of the new one) for the formalized presentation of knowledge domain and corresponding computer ontologies;
5. practical implementation of the project.

These stages are organized in a linear sequence, but have also feedbacks.

4. Basis of Ontology-oriented Support for TD Research

The research methodology and design of the mechanism of ID interaction in solving complex scientific and technical problems are associated with the creation of a conceptual framework of scientific theories. A set of $\langle C, R, F \rangle$ formal computer ontologies of specific knowledge domain may be such a framework. Formally, such an ontology can be represented by four sets:

$$O = \langle C, R, F, A \rangle, \tag{1}$$

where C, R, F, A — finite sets respectively: C — concepts of knowledge domain, R — relationship between them, F — interpretation functions (both C and R), A — axioms [10], [13].

The implementation of the ontological concept involves a complete description of knowledge domain, for this it is necessary: 1) to form and process (perform semantic analysis) the integrated linguistic corpus of texts by given subject areas; 2) to build ontographs (sets *C, R)* for each knowledge domain; 3) to formalize descriptions of knowledge in the form of a scientific theory; 4) to carry out procedures of processing and integrating subject knowledge using semantic analysis systems of source text materials and analytical processing and presentation. An example is the toolkit *Polyhedron* (transdisciplinary ontological dialogues of object-oriented systems), which is presented as a complex of program-informational and methodical knowledge management tools using approaches of ontological management of corporate information resources [14].

The role of ontologies of subject knowledge, besides the traditional functions of conceptualization and specification of scientific theories, is in the implementation of ontological management at the level of computer system architecture.

In more detail the categorial and domain levels of knowledge in the scientific and ontological picture of the world are presented in Fig. 5. It is clear that all aspects (even basic ones) of the indicated levels of knowledge cannot be reflected in one scheme. Therefore, here the emphasis is on the category "Nature → Society → Man → Knowledge of the World → TD scientific research". The figure shows three generalized levels.

The Fig. 5 shows three generalized levels.

1. Properly, the actual level of categories, structured into six sublevels (0 ÷ 5) in accordance with the categorial relationship.
2. The level of domains of subject and scientific disciplines. It is divided into three sublevels (1 ÷ 3), which mainly reflects the domains of the branch of science. Starting from this level, the semantic relations between concepts are already amenable to some scientific understanding. Most of them are represented by "be whole", "be part", "be species" and "be genus".
3. The level of disciplines is represented only by the root vertices of the subject disciplines and technologies of the sixth technological structure. At this level, "whole-part" relationships prevail. Let us briefly describe the levels listed above.

Categorial level. An unshakable rule for constructing any ontograph is to indicate the root vertex concept, which includes in its scope all the underlying vertices-concepts. In this case, such a vertex is the category "Universe" (B) (level 0). Formally, B is a type of the highest (zero) level of categorization, has no differentiation [5], [13].

Level 1 contains the categories "Cosmos", "Noosphere", "Object" and "Process". The category "Cosmos" on the presented ontograph (see Fig. 5) is not considered in detail (at this stage). The category "Noosphere" is represented by the ontograph (see Fig. 4). The categories "Object" and "Process" are included to separate concepts into static and dynamic types. The ontograph does not contain the categories "Material" and "Abstract", because the thematic focus of the ontograph involves the inclusion of mainly abstract concepts.

The categories of sublevels 2 ÷ 4 reflect the essential basis of TD research, and the categories of sublevel 5 detail them.

The level of domains plays an important role in the formation of "convergence clusters" organically connected set of scientific theories, modem technologies and technical branch achievements. The indicated coherence is clearly manifested in the above-mentioned NBIC-technology cluster.

The level of disciplines specifies the subject disciplines, scientific theories and technologies. The scheme of categorial level of concepts (see Fig. 5) is structured in accordance with ontological principles, the logical law of the inverse relationship between the volume and content of concepts and claims-statements that are recommendatory in nature [13].

5. Information Technologies of Supporting TD Research

Currently, the development of science is characterized by increasing trends of integration in the study of objects. This is because modem science explores complex and self-developing systems that require cooperative interaction of various scientific disciplines. So, ecology, general systems theory, cybernetics, informatics, and sociobiology are examples of a complex of natural science, technical, and humanitarian research. In particular, there is a well-known approach to the description of complex reality, which is connected with the ideas of constructing artificial intelligence, in particular, with its sections: neurocomputing, pattern recognition, multi-agent systems, decision making and

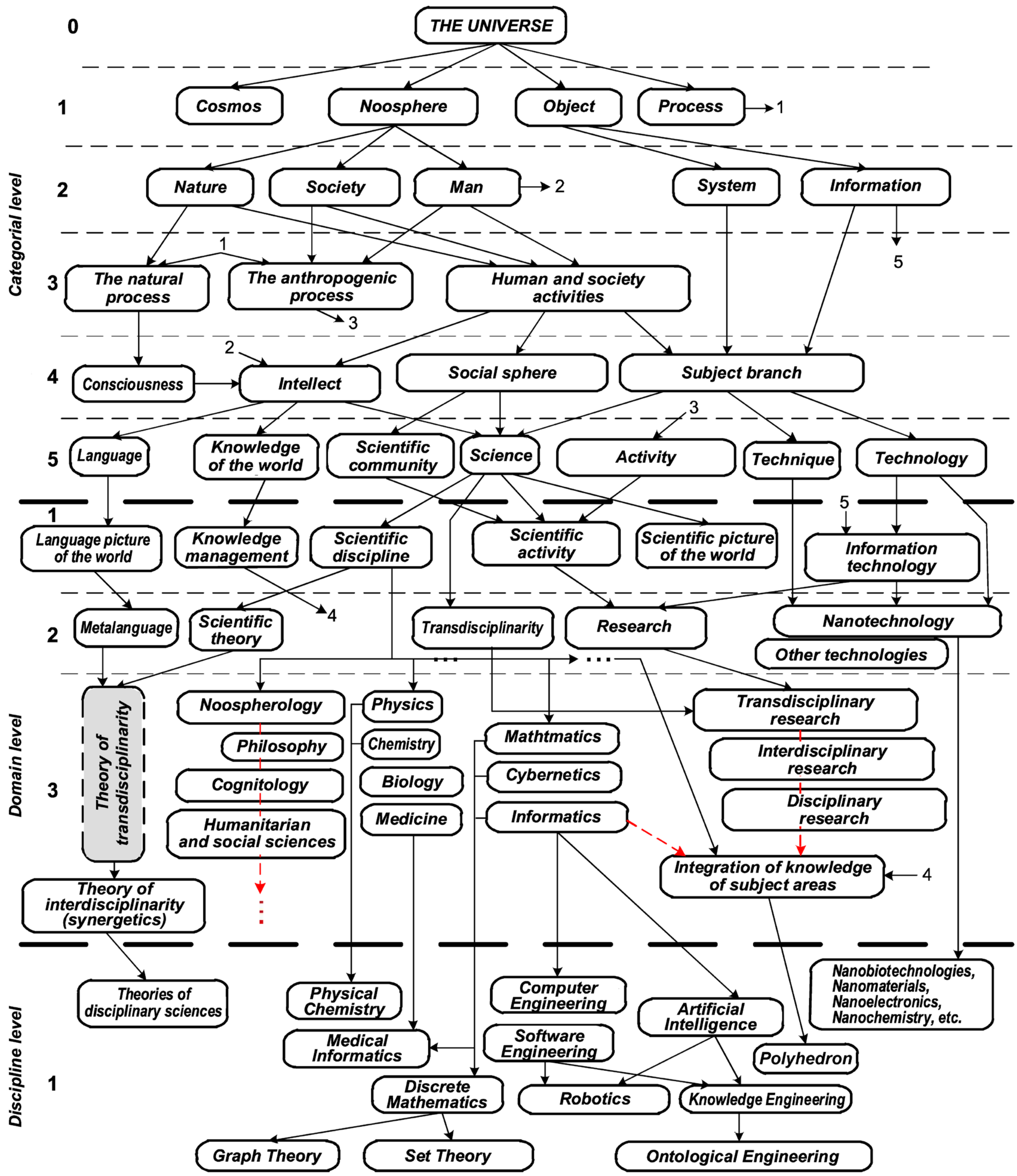

Fig. 5. Scheme of interaction of concepts of categorical level

expert systems, developing intelligent information systems.

Fig. 6 summarizes in the generalized form the interaction of the pair: “Transdisciplinarity ↔ Computer Science”.

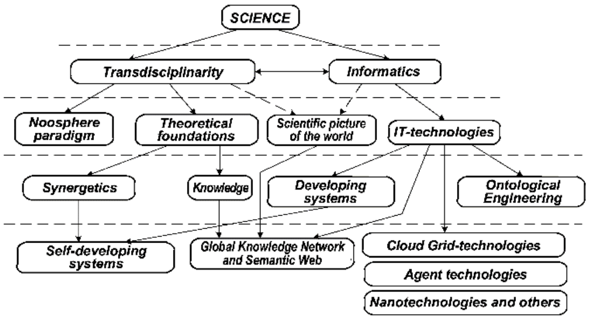

Fig. 6. Scheme of interaction of the pair “Transdisciplinarity ↔ Computer Science”

Development and application of intelligent information systems (IIS) in various areas of human activity led to the creation of IIS of a new class, combining the properties of TD, ontological management, united by the concepts of purposeful development and virtuality. This is TD class of developing ontology-driven systems of research design. In addition to the tasks of infrastructural support for scientific research, here the tasks of their methodological support and ensuring the processes of integration, convergence, unified representation of TD knowledge and operations on them come to the fore. A significant role is played by systemological skills training and expansion of range of worldviews of scientific researchers to ensure the dual unity of the concepts of deepening knowledge in a particular subject area, on the one hand, and expanding the scope of the problem, based on the reality of the unity of the world and need to form a unified system of knowledge about the world, on the other hand [15].

From the positions under consideration all the evolving information systems can be divided into four interrelated classes: genetic; with virtual architecture and reconfiguration; knowledge-oriented; transdisciplinary.

In addition, they include two fundamentally different subclasses: autonomous and nonautonomous systems. The latter are intended for active human-machine interaction, or more precisely, natural and artificial intelligence. Examples of intelligent technologies and computer systems such as “Systems of research design”, “Multi-agent technologies and neurocomputing”, “Grid-computing and cloud computing” are considered in [5].

As stated above, the fields of application of TD studies are constantly expanding, which, in turn, requires the continuous improvement of information (including supercomputer) technologies to support them. At the same time, the social component is added to the requirements, for which the parameters of reliability, efficiency and safety prevail. When considering the process of natural development of science and increasing demands on it by society, an integrated information technology system, which provide organizational processes, monitoring of scientific research, regulates all stages of their life cycle and electronic document management, analysis and evaluation of research results, decision making and determination current trends, etc., should be a basis for managing TD research. As a result, a common integrated space TD-knowledge is created, where synergistically many teams of professionals from different subject areas can interact, which will focus on solving the most important TD scientific and practical problems [16].

The core of integrated information technologies for TD scientific research consists of systematically integrated bases of structurally presented knowledge, distributed knowledge-oriented services, providing highly organized access to information and computing resources, the performance of such functions: identification of patterns, support of decisions making, cooperative collaboration virtualization, outsourcing, application of modern methods of processing multimedia information resources in virtual hyperspace.

Transition from the nondeterministic mode of production and use of knowledge by subjects of the scientific process to the mode of effective knowledge management, presented in a unified form at all stages of their life cycle, will ensure the growth of the effectiveness and quality of scientific research. At the same time, sustainable knowledge will become an intellectual capital, and the subjects of science will be direct participants in the economic activities of the society, which will create favorable conditions for stimulating the development of both science and creative society [16].

TD in turn puts forward the requirement of integration of scientific disciplines on the basis of formalism, common to all subject areas. This is the formal computer ontology. Hence, the process of noospherogenesis is based on the paradigmatic tuple (*noosphere-SPW-transdisciplinarity-ontological concept-applied intellectual systems and technologies)*.

So, let us formulate an open (complemented and developing) system of requirements to information technologies supporting TD research.

1. New computer technologies should be built on the basis of knowledge adequate to the processes of solving problems in science, nature and society.
2. Continuous improvement of both the technologies themselves and the methods of manipulating them.

3. Information and knowledge have the property of idempotency, and therefore information technologies must support this property (information sharing and knowledge sharing).
4. Promising modem methods of processing data, information and knowledge should be supported, including: close interaction with Grid-, Cloud- and Supercomputer technologies; ability to handle large amounts of data (Big Data); multi-factor authentication; focus on Green Computing (environmental technologies).

6. Conclusion

V.I. Vernadsky teaching about the noosphere in its essence appeals to the SPW, which must be built in order to overcome ID barriers and increase effectiveness of interdisciplinary interaction and modern science in general. It is about creating universal TD knowledge.

The development of the NBIC-cluster of convergence opens wide, so far completely not assessed, possibilities of a global knowledge-oriented Internet, but with it also the whole of modern civilization. Obviously, this development will follow first the path of creation of the applied distributed systems in specific subject areas (Internet of things, smart systems in telemedicine, environmental monitoring, information support of goods and services, energy systems, utilities, etc.). Grid-, Block-chain-technologies and Cloud-computing, as well as virtual organizations, structures and services will occupy the central place in them.

Thus, the problems of effective support for scientific TD research will lead to the formation and systems analysis of the service-oriented paradigm of noospherogenesis, transdisciplinary approach, ontological concept, the SPW, taking into account promising and informational technologies. The essential function of this paradigm is fully defined and, in fact, makes the methodological basis of modern scientific research as the basis for the development of civilization. Noospherology, as noted above, is a complete body of knowledge that ensures harmonic interaction in the "Man-Nature" system under the control of scientific thought and the will of man. It is organically linked with the scientific and technological components of the development of civilization. The development of science has moved from the stage of differentiation to the stage of integration, making it possible to implement the TD concept of the development of science, which appeals to SPW in the formulation and conducting of research and implementation of complex research projects. Without it, a purposeful positive process of noospherogenesis is unthinkable. Here informatics fulfills its mission as a backbone branch of knowledge. An ontological concept has arisen in its depths, the essence of which consists in the formal ontological description of subject regions and SPW as a whole. Finally, modem information technologies have already become the basis of almost all Hi-Tech and construction of knowledge-oriented society, capable of resolving all essential contradictions of the development of modem (technological) civilization.

7. Credit Authorship Contribution Statement

Mykola Petrenko: Supervision, Conceptualization, Methodology, Writing – original draft.

Kyrylo Malakhov: Validation, Resources, Term, Writing – review & editing.

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