Application of Space-Time Patterns in Tutoring

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Abstract. The inevitable increase in the diversity of information flows, their processing and visualization methods exacerbates interdisciplinary problems. They lead to cognitive bias, which limits the potential of IT and intelligent learning systems. Therefore, the aim of the work is to expand interdisciplinary relations through the use of complementary space-time signatures and patterns of functioning of self-organizing objects.

The object of research is the system "student – cognitive environment – teacher", the functioning of which is determined by the interdisciplinary ergonomic laws of mutual adaptation and transformation. They are a generalization of the extreme principles of physics, as well as the principles of cybernetics, synergetics, computer science, etc.

The cognitive visualization of the spatio-temporal structure of fractal signals of various nature in the form of signatures and patterns is carried out. The basis of visualization – interdisciplinary – approach, methods, concepts and criteria. This allows us to identify hidden patterns of functioning of self-organized dynamic systems. The use of signatures and patterns of fractal signals of self-organized objects will contribute to the development of critical thinking and intuition in learning and also promising for machine learning.

Keywords: Intelligent Learning Systems, Spatio-Temporal Topological 3D Model, Functioning Patterns, Interdisciplinary Communications, Cognitive Patterns.

1 Introduction

Digitalization of industry and education (Industry-4.0) highlighted their current problems [1]. Thus, the inevitable increase in informational diversity complicates the cognitive perception of formalized information and limits the possibilities of IT and ICT in learning. Cognitive ergonomics indicate the need for individualization of learning [2-4]. The transition to continuing education requires intellectual support for the individualization of instruction. This can be realized only on an interdisciplinary basis through overlapping subject fields and their structuring [5]. Therefore, the unification of the means of visualizing information flows of different nature is relevant. In the context of informatization of education, adaptive learning tools based on ICT are of particular importance. With their help, you can also take into account the psychophysiological capabilities of a person during learning. However, to date, no systemic ideas have been formed on how and with what means it is possible to build an individual learning path.

2 Statement of the problem

Problems of perception and assimilation of the variety of educational information. Today the problem of the dependence of perception and assimilation of educational information on informational complexity has become more acute. It, in her opinion, affects the psychophysiological state of the student. These are cognitive problems that are caused by: a) the variety of definitions of information and its measures; b) a variety of means of processing and visualization of information; c) different interpretations of certain terms in different subject fields. The consequence of this is the study of complex processes using simplified models, which does not stimulate the development of individual abilities and cognitive abilities of a student. Therefore, the cognitive aspects of perceiving informational complexity are relevant [6, 7]. Small structuredness, fuzziness and blurry information leads to the manifestation of hidden relationships (fig. 1)

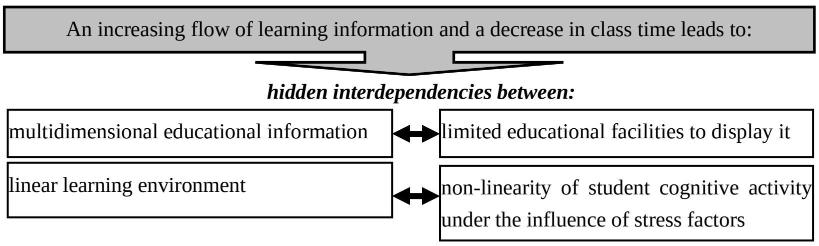

Fig. 1: Hidden relationships

In the traditional organization of training, the psycho-psychological and cognitive capabilities of the student are not taken into account (the speed of perception and assimilation of information, the speed of response to stimuli, periods of study and rest, etc.)

Purposeful approaches to learning - transformational, ergonomic, adaptive - use the general principles of self-realization and are based on the same ideas: motivation, self-study, acquired experience. Within the framework of the methodology of each of the approaches, it has not yet been possible to develop an effective methodology for individualizing learning. Therefore, the main purpose of this article is to expand interdisciplinary relationships through the use of coplanar spatio-temporal signatures and patterns of fractal signals.

According to the theory of Scott A. Snook, the expected ability to learn and the calculated trajectory differs significantly from the result obtained (Fig. 2).

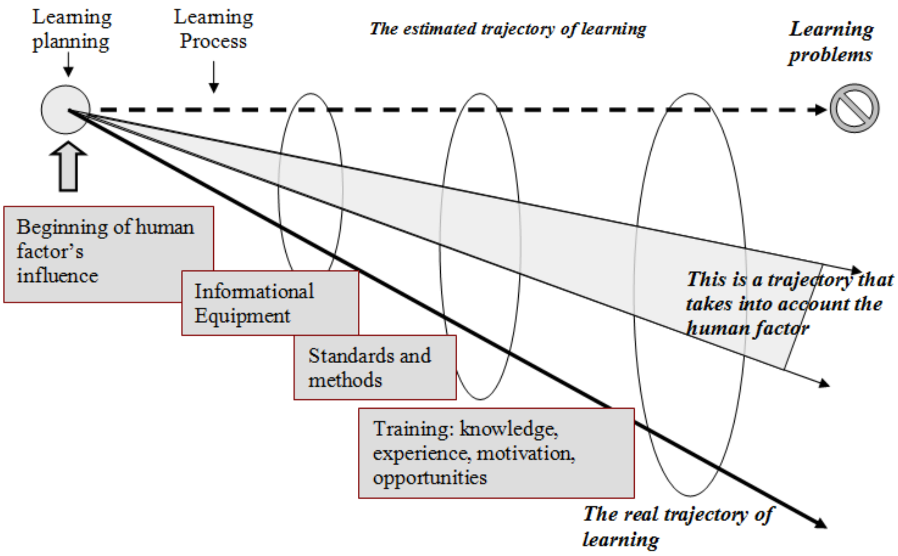

Fig. 2: The causal interdependence of the success of learning, taking into account the individual abilities and plans of the student

Therefore, to build individual learning paths, the updating of interdisciplinary connections is necessary, which will allow taking into account the individual capabilities of the student [8, 9]. It should be focused on the structuring of information arrays, the visualization of which contributes to the development of critical thinking. In our opinion, the actualization of interdisciplinary connections can be realized through geometrization of the dynamics of functioning of self-organized sources of information (smart sensors, biosensors, etc.). Indeed, the dynamic similarity of structures of different fractal signals simplifies their cognitive perception and assimilation. Therefore, the expansion of interdisciplinary relations will contribute to an integrative perception of the natural sciences and the development of cognitive science.

3 Visualization of the structure of information flows

Information on interdisciplinary communication. It is hidden in the features of the functioning of dynamic systems of different nature in difficult conditions. Their dynamics are determined by the interdisciplinary laws of mutual adaptation and transformation. They are the result of the complementarity of the extreme principles of physics (Hamilton, Lagrange, Jacobi and others) and the dynamic similarity of self-organizing processes of different nature. These principles of dynamics are interconnected and have a geometric interpretation (G. Hertz principle) as well as the Gaussian energy interpretation. In particular, on the basis of the variational principles of dynamics, a connection is established between the symmetry of the physical system and the conservation laws (E. Noether theorem). These principles underlie the theory of optimal control and can be applied for intellectual computer support of self-learning.

The use of analogies and dynamic similarity in modeling processes. The peculiarities of self-organization are manifested in opposition to the impact, which displays the thermodynamic principle of Le Chatelier-Brown. Therefore, the application of the laws of mutual adaptation and transformation and the Le Chatelier - Brown principle for the analysis of dynamic processes makes it possible to study the spatio-temporal cyclic nature of induced processes in self-organized objects of different nature. Individual features of such processes are manifested in the structure of all sources of information (sensor, biosensor, fractal signal) under external influence. Therefore, a comparison of their structures simplifies the establishment of interdisciplinary connections, and physical analogies and dynamic similarity of processes of different nature allows them to be modeled.

Parametric geometrization of biosignals. We investigated the individuality of electrophysiological signals (ECG, EEG, EOG and rheograms) from the PhysioNet database [10]. The reconstruction of the spatio-temporal model based on the functioning signal was carried out in the parametric space of dynamic events [11, 12]. In this space, each event is determined by calculating a dynamic cycle (state - a small change in speed - a small change in acceleration - a small change in state). Therefore, in the space of dynamic events (state-velocity-acceleration), a scalar time series (fractal signal of any nature) is transformed into a sequence of dynamic events in the form of a topological 3D model.

Topological 3D model of a biosignal. Digital differentiation of a human cardiosignal X (t) allows transforming it into a phase portrait that displays a sequence of dynamic states in space (state-speed-time) (Fig. 3, a). Repeated differentiation allows you to display it in space (state-speed-acceleration) in the form of a trajectory of discrete dynamic events (Fig. 3, b).

Orthogonal projections of the 3D model of the ECG are dynamic, energy and information signatures of the 1st and 2nd orders. In their configurations, latent spatio-temporal features of the cardiocycle are most manifested. From a comparison of Fig. 3 (a) and (b) it follows that the phase portrait of the cardiocycle is a first-order signature (plane a). However, the signature configuration as a sequence of geometrically ordered components is more informative. The signature area is proportional to the power of microstates, the natural logarithm of which is proportional to entropy [13].

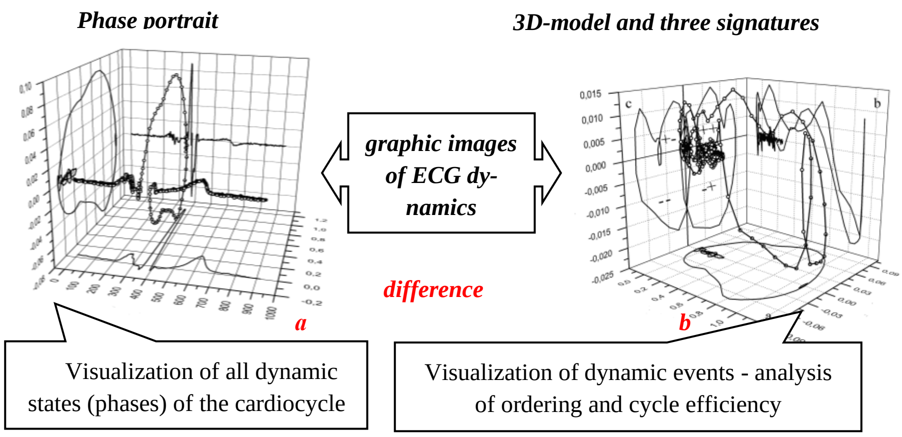

Fig. 3: Phase portrait and 3D models of the human cardiocycle as a sequence of dynamic states (a) and dynamic events (b)

The individual characteristics of the configurations of the first and second orders of fractal signals are due to the hidden structure of the relationships between spatial and temporal heterogeneities, which are induced by stress factors of different nature [11-13]. Using original digital filters, signature configurations can be transformed into their patterns. Note that a comparison of signal signatures with their patterns allows one to find such patterns (solutions) that are individually not reachable by either the computer or the human brain.

Visualization of quasiperiodic fractal signals of various nature in the form of a package of signatures provides qualitatively new opportunities for learning and modeling. The batch representation of signature configurations reflects the nature of the restructuring of the cardiocycle structure (Fig. 4).

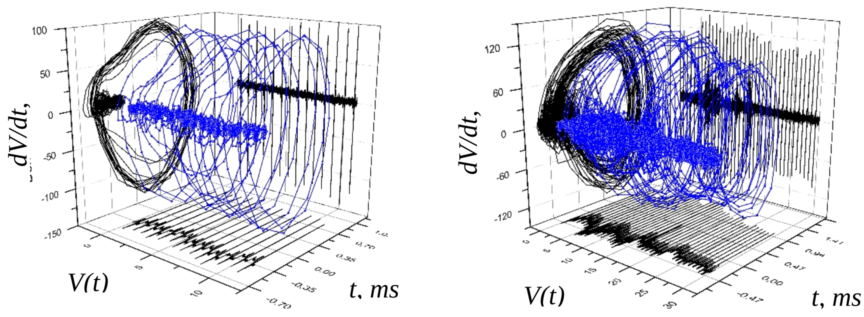

Fig. 4: Visualization of the nature of the restructuring of the dynamics of the human cardiocycle

In the nature of the change in signature configurations, a counteraction to external (internal) influence is visualized. Using the analysis of the restructuring of signature configurations, stress factors (information attack, etc.) can be identified and consequences can be predicted by the nature of the restructuring of their structures (for example, the state of human stress, Fig. 4).

The transformation of spatio-temporal signatures into patterns using original digital filters allows us to study the relationship of the structure with the functionality of the information source. Patterns and signatures are complementary graphics. Signatures allow you to identify a hidden personality and establish patterns, and their transformation into patterns - simplifies design, analysis, etc.

Informativeness of spatio-temporal signatures. Dynamic similarity of signature configurations. In various subject areas of knowledge (programming, mathematics, technical and medical diagnostics, predictive analytics, and some others), the concept of signature is defined differently. However, most of them are used to identify an unknown source of information through comparison with a standard (model, pattern). Signature configurations of the 1st and 2nd orders display the decomposition of the signal into geometrically ordered components, and their areas reflect the intensity of antiphase processes. Signature configurations of different information sources are perceived as a sequence of maxima and minima. Signature features can be described both by mathematical terms-antonyms and physical terms-antonyms. An analysis of signal signatures at three complementary viewing angles allows revealing the structure of hidden relationships. It is characterized by integrative indicators of dynamic ordering, energy balance and information complexity.

Informative characteristic features of signature configurations are: a) symmetry / asymmetry; b) the covered area and its distribution by quadrants; c) the number of geometrically ordered components; d) the ratio of partial contributions of antiphase components. Together, they allow us to study and evaluate dynamic processes in different subject areas.

Cognitive characteristics. The ability to identify and classify is one of the fundamental mental and subject-cognitive abilities of a person and is associated with all cognitive functions. Cognitive characteristics of configurations of signatures and patterns of information flows of various nature stimulate thinking in more general forms. Moreover, the use of intuition contributes to the acquisition of new knowledge. After all, we prove with the help of logic, but we discover through intuition. So, the identification of information sources (objects, properties, a set of states, etc.) using signatures and their patterns increases the use of figurative thinking. It contributes to the development of intuition in learning and is important for the individualization of learning.

Spatio-temporal signatures and patterns as cognitive models. The principle of mutual ordering is manifested in the spatio-temporal ordering of the component configurations of the signatures of fractal signals. This confirms the idea of N. Wiener that the most general form of signal organization is its linear invariant. Further disclosure of the concept of the configuration and structure of the information flow allows us to move from a linear invariant to the concept of mutual ordering of two sets. This principle of mutual ordering of two sets is defined by the concept of spatio-temporal isomorphism. It is implemented in the configuration of signal signatures and makes them code. This, as well as evaluating the entropy, orderliness and balance of the functioning cycle, turns the 3D model and the signatures of information flows into cognitive graphic images. Their digital transformation into patterns activates the imaginative (right-hemispheric) thinking of the student during learning, and also contributes to the development of intuition. Therefore, spatio-temporal signatures / patterns of fractal signals can serve as cognitive models of cognition of reality.

Cognitive space. The concept of cognitive space was first introduced by Newby G. It is presented as a multi-structured formation, which includes many aspects (cognitive, semiotic, psycho-physiological, etc.). The multidimensionality of hidden spatio-temporal features of information flows is most manifested in the space of dynamic events. Therefore, the singularities of the evolution of self-organized objects are closest to psychological patterns (behavior, experience, etc.).

Machine (inductive) learning. Today, inductive learning is characterized by an established set of methods and its key interdisciplinary terminology. Naturally, the basic procedural knowledge of most subject areas includes the extreme principles of physics, the Le Chatelier principle, conservation laws, the principles of thermodynamics, the principles of synergetics, etc. Therefore, using spatio-temporal signatures and patterns, one can study the dynamics of complex processes of different nature in cognitive space using universal tools. At the same time, the similarity of pattern configurations of different subject areas simplifies the solution of closely interconnected interdisciplinary problems and tasks.

4 Conclusions

The incompatibility of the types of information visualization does not allow revealing hidden spatial and temporal patterns of the functioning of elements of dynamic systems, including the psychophysiological state of a person. Cognitive visualization of the spatio-temporal structure of fractal signals of various nature contributes to the development of a field-independent cognitive style of information processing. It is based on the conversion of a one-dimensional time series (electrophysiological signal, sensor response, etc.) into parametric signatures of the 1st and 2nd orders of the space of dynamic events. Their subsequent transformation into patterns simplifies identification and classification, as well as reveals patterns that are hidden in signals.

The application of this technology to an interdisciplinary study of information sources of various nature (EMR sensors, radiation and acoustic radiation detectors), as well as to electrophysiological signals of a human body (EEG, EOG, rheogram, etc.) demonstrate advantages. In particular, new opportunities have emerged for revealing hidden spatio-temporal relationships that determine the features of the functioning of dynamic systems in difficult conditions. The unification of the processing of digitized information flows of various nature and their cognitive visualization in the form of spatio-temporal signatures, as well as their digital transformation into patterns, opens up completely new possibilities for personalizing learning.

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