Information & Security

V. Mygal & G. Mygal
vol. 43, no. 2 (2019): 134-144
https://doi.org/10.11610/isij.4312

Published since 1998

ISSN 0861-5160 (print), ISSN 1314-2119 (online)

Research Article

# Problems of Digitized Information Flow Analysis: Cognitive Aspects

***Valeriy Mygal*** (✉), ***Galyna Mygal***

*National Aerospace University "KhAI," Kharkiv, Ukraine*
*https://khai.edu/ua*

ABSTRACT:

The problems of security, reliability and sustainability of digital transformation, cognitive computing and artificial intelligence have common causes and origin. The inevitable increase in the number of information sources leads to ambiguity and inconsistency of the analyzed information. The variety of ways to display it makes it difficult to make effective decisions by a pilot, dispatcher, and other operators. The key security problems of dynamic systems are: a) the variety of means of displaying information sources, b) the lack of universal means of analyzing the flow of digital information, c) the individuality of the functioning of information sources when exposed to stress factors. The unification of cognitive visualization of information from sources of a different nature on an interdisciplinary basis simplifies the solution of these and related problems. The visualization of the structure of various sources of information in the form of dynamic patterns and their comparative analysis in one space allows to identify relevant internal and external sources of information. In the restructuring of patterns, the dynamic and statistical features of their functioning are displayed. The integration of digital technologies makes it possible to identify sources of information, predict their vulnerability, and also solve the problem of effectively selecting information sources.

ARTICLE INFO:

RECEIVED: 23 MAY 2019
REVISED: 09 SEP 2019
ONLINE: 21 SEP 2019

KEYWORDS:

man-machine interaction, relationship of structure and functions, signal structure, cognitive visualization



✉ Corresponding Author: Tel.: +38 050 756 0829; E-mail: valeriy.mygal@khai.edu

## Introduction

Digital transformation, cognitive computing, and human-machine interaction are an integral part of the general tasks of analyzing the flow of digital information.[1] The inevitable increase in the number of sensors and other sources of information leads to many problems.[2] A person is able to take into account at the same time no more than 5-7 factors that influence decision making. At the same time, external and internal factors can distort information flows (sensor signals, material characteristics, etc.). These factors especially affect the psychophysiological state of a person. They can lead to cognitive impairment (see Fig. 1).

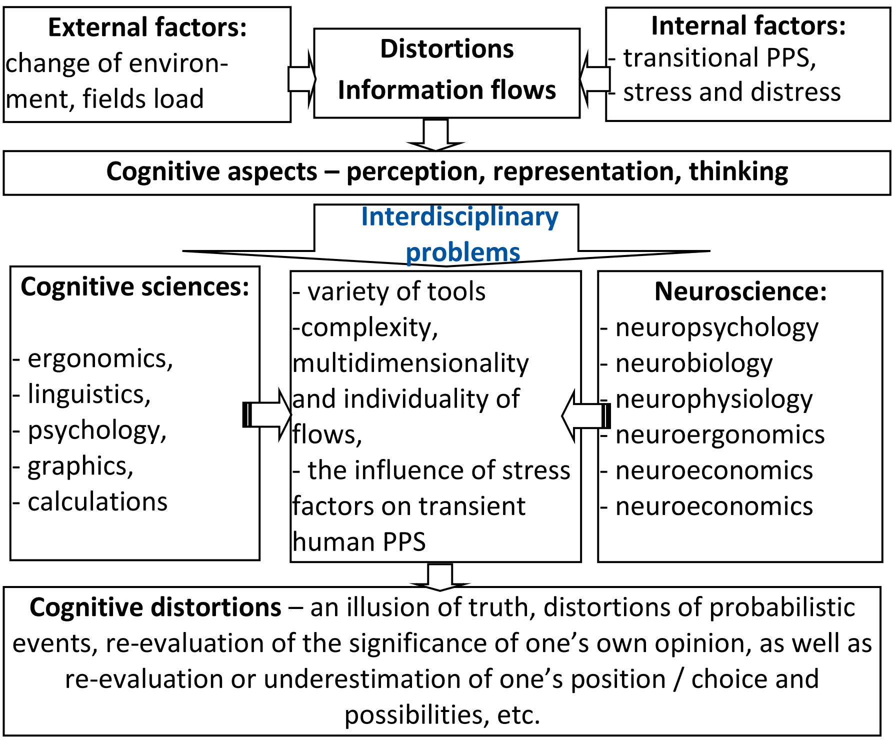


**Figure 1: Interdisciplinary problems of analysis of distortion of information flows.**

As one can see in Figure 1, there are five interdisciplinary problems. The first is diversity (processing methods, types of visualization, methods and analysis tools). The inevitable increase in the number of information sources (sensors, etc.) in complex dynamic systems increases the uncertainty and ambiguity of the analysis of digitized information. The second problem is the complexity of the signal, its multidimensionality and non-linearity. They complicate the perception of information, its presentation and require the development of nonlinear thinking. The third problem is that external and internal stress factors affect sensors and other sources of information. So, force fields of various nature (radiation, etc.) are factors that distort information flows. At the same time, spatio-temporal inhomogeneities arise in them, which affect stability, sensitivity and other characteristics. Therefore, it is necessary to use sensors that are resistant to intense (radiation, field and other) loads. The fourth problem is the influence of transitional psychophysiological states (PPS) on the adoption of the optimal decision by the operator (pilot, dispatcher, etc.). The identification of these states makes it difficult to nonlinearity and fractality of electrophysiological signals. Information about the features of PPS is hidden in the spatio-temporal features of electrophysiological signals (ECG, EOG, EOG, etc.). Their individuality is little manifested in the well-known graphic images of these signals (phase portraits, rhythmograms, patterns, etc.). The fifth problem is related to the use of simplified mathematical models, which are determined by differential equations. These models are effective in the natural sciences. Such analytics is redundant in definitions, and also considers cases that cannot be implemented. The functioning of natural information sources is described by non-linear differential equations, the analysis of which deals with many scenarios. However, in this analytical approach there are no means by which we could distinguish between the real and the possible.

The analysis of digital information flows also complicates: a) insufficient complementarity of processing methods for various information flows, b) multidimensionality and fractality of natural information flows, c) a variety of patterns and models. They limit the possibilities of computer graphics methods. There are also difficulties in obtaining such graphic images that do not cause direct object associations in the decision maker.[3] Consequently, cognitive visualization of time series (signals, responses, etc.) on an interdisciplinary basis is necessary. The processes of organization (structure) of managing objects of animate and inanimate nature are similar to those elaborated by Norbert Wiener.[4] Therefore, for the associative perception of processes of various nature, it is necessary to unify the means of visualizing their structure. It is a comparison of the structures of the flow of digital information of various nature that eliminates the ambiguity of cognitive graphics and its interpretation. By comparing the structures of information sources, one can stimulate systemic thinking and develop intuition. This possibility is indicated by the analogy between the processes of pattern recognition in cognitive processes and the dynamic processes of the formation of natural systems.[5]

Analysis of the signals of sensors of various nature (biosensors, etc.) as information flows simplifies the search for external and internal risk factors, which are also sources of information. The structures of natural information sources are most sensitive to the intensity and dynamics of the force field. In addition, most stress factors can be considered as an "information attack" with unpredictable effects. Therefore, the dynamics of information flows of different nature can be considered both in the information and in the physical space. The application of an interdisciplinary approach to identifying individual features of the functioning of objects allows us to analyze the interrelated parameters of the dynamics of information flows of different nature.[6] The application of this approach to cognitive visualization and analysis of digital information flows of different nature was the main goal of the work.

## Visualization of the space-time structure of information flows

The individuality of information sources (sensors, detectors, spectrometers and others) is manifested in the complexity of the signals, which is due to local distortions (heterogeneity, instability, etc.). They are interconnected internal micro-sources of information that generate spatio-temporal heterogeneity of information flows. To identify them, it is necessary to convert the dynamics of a one-dimensional signal into statics. For the first time, the idea of reconstructing a model of functioning from measured signals (scalar time series) was proposed by Packard in 1980.[7] Then, in 1981, it was formalized by Tackens in the form of a theorem on the embedding of a time series in $R^n$.[8] However, it is difficult to analyze complex sensor signals. The source of information contains features that determine the individuality of functioning. These features are due to the structure of the spatio-temporal relationships of micro-sources of information, the nature of which no longer matters. The coordination of the functioning of different sensors depends on the orderliness and balance of the structure of interconnections by micro sources of information. Therefore, the spatio-temporal inconsistency of the structures of information sources affects the effectiveness of man-machine interaction. Most stress factors can also be considered as an "information attack," which can affect the structure of the relationships between microsources of information.

Identification of individual features of the spatio-temporal structure of signals of different nature is possible through their visualization in the space of dynamic events. The basis of the approach is the variational principles of dynamics. Their use in various sciences (continuum mechanics, thermodynamics, electrodynamics, field theory, synergetics, etc.) made it possible to weaken the mathematical restrictions as much as possible. In particular, these principles lie at the origins of the theory of optimal control. The complementarity of different approaches to extreme principles indicates their fundamental nature. In particular, the principles of least action (Hamilton, Lagrange, Jacobi, etc.) imply the differential principle of least curvature or Hertz distance.[9] And the principle of least coercion of Gauss can be given an energy interpretation. The thermodynamic principle of Le Chatelier-Brown follows from them (opposition to external influences). An obvious consequence of the connection between the symmetry properties of the physical system and conservation laws (E. Noether's theorem)[10] is a dynamic similarity of the reaction processes that form fractal properties during self-organization objects of different nature.

The evolution of the dynamic state X (t) of an information source (sensor, etc.) is usually analyzed in a generalized phase space (state - speed - time). At the same time, application of the extreme principles of mechanics to the information flow allows us to move from a deterministic description of the dynamics of the sensor signal to a probabilistic description of the signal as a set of micro-sources of information. To do this, in the generalized phase space, we replace the time axis t with the acceleration axis $d^2X / dt^2$, which converts it into a parametric space (state – speed – acceleration). This is the space of dynamic events in which each point with coordinates $\{X, dX / dt, d^2X / dt^2\}$ represents the probability of the $i^{th}$ event. For a probabilistic description of the evolution of the dynamic state $X (t)$, we apply the extreme principles to its small changes, as well as to small changes in the velocity $\delta((dX (t) / dt)$ and acceleration $\delta(d^2X (t) / dt^2)$. In this case, the scalar time series X (t) (digitized signal, response, characteristic of the sensor or biosensor, information flow) is converted into three state dependences on time $X_i (t)$, $dX_i (t) / dt$ and $d^2X_i (t) / dt^2$, which are naturally interconnected. Therefore, the display of the natural signal in space (state – speed – acceleration) turns the scalar time series into a discrete sequence of dynamic events in the form of a topological 3D model of the operating cycle [11, 12] (see fig. 2).

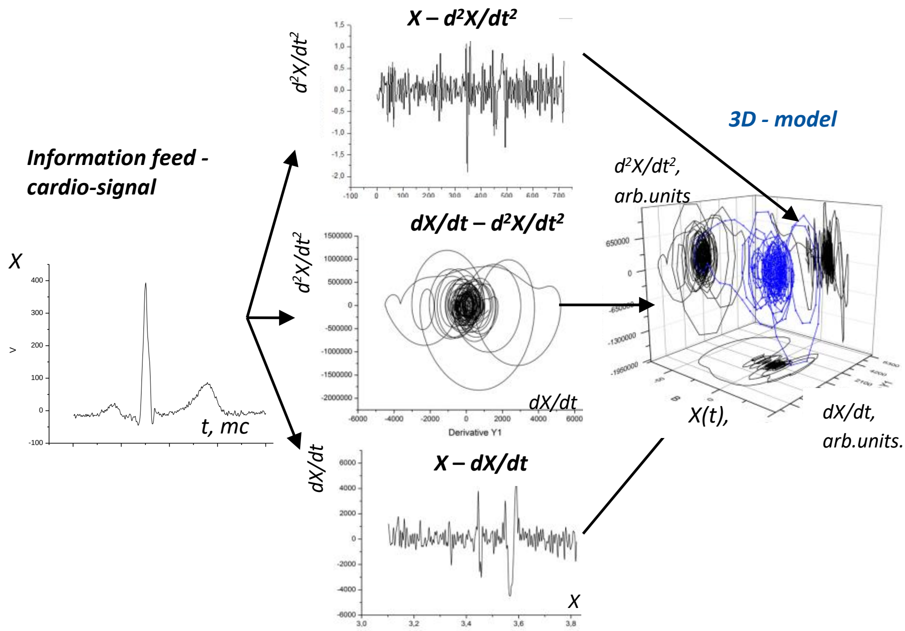


**Figure 2: Transformation of information flow dynamics to signatures of information sources.**

As can be seen from the figure, the geometrization of the information flow is accompanied by natural decompositions into components that differ in the intervals between events. The spatio-temporal ordering of the components is most evident in the orthogonal projections of the 3D model of the functioning cycle. The configurations of these projections are individual graphic images —

signatures of a source of information of the first and second orders.[13] They are closed sequences of geometrically ordered sections that differ in length, steepness or curvature. These components distinguish processes (physical, biological, information, etc.), which are characterized by the constancy of speed or acceleration, respectively. In addition, statistically these sections differ: a) the linear density of dynamic events, b) the distribution in the corresponding subspace. Significant statistical parameters of signatures are subsets of microsources whose powers are proportional to the areas of signature configurations of the 1st and 2nd orders. The areas of these signatures of the 1st and 2nd orders of the information source have dimensions that allow us to analyze the dynamic, energy, and informational features of the functioning of the information source (sensor, etc.). This allows you to combine dynamic and statistical methods of analysis (Fig. 2). The individuality of the signal in: a) the number and variety of interrelated characteristic features of the configuration of the signatures and their partial contributions, b) the dynamic structure of the interconnections of its components, c) the power of many microsources of information and the nature of its distribution according to the quadrants of the signature.

## Signature analysis of the structure of information flows

For natural sources of information of a different nature (sensor signals, biosensors, characteristics of reasonable materials, etc.), signature configurations are similar in presentation form. This allows you to unify their analysis tools. Signatures, on the one hand, simplify the comparative analysis of the functioning structures of different sources of information. On the other hand, signature analysis provides a qualitatively new opportunity for cognitive perception and analysis of the dynamics of processes of different nature. In particular, when the situation changes quickly, signatures make it possible to understand which 5–7 relay-related parameters. We draw attention to the fact that in the theory of self-organization—*synergetic*—the order parameters that determine the organizational structure are relevant. In signatures, the order parameters are entropy and a measure of balance, which reflects the degree of asymmetry.

Consider the new possibilities of cognitive perception and analysis of signatures of the 1st and 2nd orders of the information source in the framework of the developed approach. The configuration of the signature

$$X(t) - dX(t) / dt$$

is perceived as a sequence of dynamic states, which is usually analyzed as a phase portrait. Therefore, in the developed approach, the fundamental principle of compliance is fulfilled – the new approach includes the well-known one. However, the signature configuration also reflects a natural decomposition into geometrically ordered components that can be captured at a glance.

When analyzing the configuration of the signature $X(t) - dX(t) / dt$, the following indicators can be used: a) the number of geometrically ordered sections *п* and their partial contributions $P_п$,[12] b) the signature area is the power of a subset of microstates W, and the natural logarithm W is proportional to the entropy H and is a universal measure of the ordering of the distribution of W,[14] c) the ratio of the areas of the antiphase components of the Hb / Hn signature. For example, for semiconductor sensors, this ratio reflects the features of generation – recombination processes.[15]

In the configurations of second-order signatures, the energy and information de-composition of signatures of information sources is most manifested. The configuration of the signature $X (t)$ - $d^2X (t) / dt^2$ displays the space-time distribution of the energy of the antiphase components. Therefore, the configuration of the signature $X (t)$ - $d^2X (t) / dt^2$ visualizes the energy balance of the information source. This signature is characterized by indicators: a) energy intensity, which is proportional to the area of the signature, b) energy balance, which are equal to the ratios of the antiphase areas of the signature. Of particular interest is the nature of the relationship of the dynamic variables $dX (t) / dt$ and $d^2X (t) / dt^2$, which displays the configuration of the signature $dX (t) / dt$ - $d^2X (t) / dt^2$. It visualizes the target management functionality, which is based on a feedback loop. The signature configuration is perceived as a spatio-temporal structure of the distribution of the power of micro-sources of information between the main phases of the functioning cycle. The signature area is proportional to its power. Therefore, the nature of the distribution of the area over the quadrants of the signal signature can be analyzed statically using the matrix of indicators of integral balance.[6]

A comparative analysis in one space of signature areas of different information sources allows to reveal 5-7 relevant information sources. The analysis of three configurations of signatures as patterns by characteristic attributes (symmetry, orderliness, balance, information complexity, etc.) allows real-time assessment of the functional state of information sources of different nature under complementary viewing angles. In particular, a comparative analysis of the 1st and 2nd order signatures of the temporal and spectral photo-responses of semiconductor sensors (photodetectors, detectors, spectrometers) made it possible to identify characteristic signs of technological heredity.[6, 13] It is also possible to analyze the information sources of elements of complex dynamic systems.

## Cognitive perception of the structure of information flows

In the ontological plane, “space” and “time” constitute a single spatio-temporal continuum. When thinking about time, a person’s thinking usually refers to spatial images, as well as to relationships and concepts. After all, when we talk about “time,” we mean “duration,” “change,” “dynamism,” “process.” At the same time, we present time as a change in spatial properties and relations. Obviously, the models of cognition of reality in a broader sense are models of knowledge and thinking. Their generalization is the concept of cognitive space.[16] It is considered as a multistructural formation, which includes cognitive, semiotic, psychophysiological and other aspects. In the space of dynamic events, physical and informational aspects of the functioning of living and non-living objects are manifested. In it, a signal of any nature, as a scalar time series, is transformed into a 3D model of a functioning cycle, the orthogonal projections of which are interconnected 2D data representations in the form of signatures of the first and second orders. In their configurations, dynamic, energetic and informational aspects are displayed that reflect the features of the structure of functioning of information sources. Signature configurations can serve as physical, geometric, topographic, and informational models of the functioning cycle. Therefore, the space of dynamic events, as well as the cognitive space, is multi-faceted, since it allows us to consider the functioning cycle from mutually complementary angles of view. Visualization of the structure of the functioning cycle contributes to the "cognitive effect" and the development of systemic thinking.

It is very important that the visualization of the spatio-temporal structure of information flows (fractal signals of various nature) in the space of dynamic events is accompanied by natural decomposition and structuring into: a) antiphase components, b) subsets of micro-sources of information representing the powers of the main phases of the cycle, ) a set of geometrically ordered components. Structural configurations are perceived holistically as a combination of ordered components and subsets that can be analyzed by deterministic and statistical methods. The combination of these methods of analyzing graphic images with their perception will contribute to the development of cognitive and analytical capabilities of a person. After all, we develop intuition when we look for similarity, harmony, analogy, and also when we compare form (scale, relationship). Visualization of the spatio-temporal structure of information flows makes it possible to evaluate relationships (order-disorder, balance-imbalance, etc.). In the configurations of signatures of natural information sources, various aspects of the self-organization of living and non-living objects are manifested. Therefore, their signatures of the 1st and 2nd order can serve as dynamic, energetic and informational patterns of orderliness and balance of information sources. In the symmetry of signature configurations and in different types of similarity (geometric, kinematic, dynamic, etc.) of its components, conservation laws are displayed, which allows the use of thermodynamic criteria of stability, reversibility, and others in their analysis.

Cognitive visualization allows the application of the flexible logic of antonyms in analysis. Features of signature configurations can be described by mathematical terms – antonyms (maximum-minimum, convexity-concavity, composition-decomposition, continuous - discrete, analysis-synthesis, etc.). The same signature features can also be characterized by physical terms-antonyms (action – reaction, source – drain, ordered – chaotic, balanced – unbalanced, symmetric – asymmetric, etc.). Therefore, signal signatures as 2D representations of naturally structured data can serve as cognitive graphic models of information sources. They allow you to identify the necessary connections and make both hemispheres of the brain work actively, while synthesizing new knowledge. The presence in their configurations of elements of geometric, kinematic and dynamic similarity expands perception and contributes to the development of intuition during learning.[17] In general, the configurations of signatures of information sources of different nature can be perceived as cognitive patterns of the functioning cycle. The variety of complementary tools for the analysis and synthesis of pattern configurations has great innovative potential.

Cognitive visualization of information flows that reflect the evolution of physical, biological, and other self-organized objects provides new opportunities. This is facilitated by the batch representation of signatures of different information source.[6, 18-20]

The nature of the restructuring of the dynamic structure of different quasiperiodic signals and sensor responses (sensors, controllers, biosensors, etc.) under the influence of stress factors is most fully displayed in their signature packets. Therefore, packages of signatures of electrophysiological signals of a person are cognitive patterns of restructuring the structure of biosignals, which reflect the nature of changes in the psychophysiological states of a person. In particular, the evolution of the entropy H of the cardiac signal and the production of entropy *dH(t)/dt* reflect the individual characteristics of adaptation under the influence of stress factors.

In essence, signature packets are cognitive patterns of the structure of the information source. The nature of signature adjustment is a marker of functional change. An integrative indicator of the restructuring of the energy balance of antiphase processes is quite informative. Its application simplifies the search for relevant sources of information that determine the functioning of complex dynamic systems in extreme conditions. Therefore, with the help of signatures one can detect stress factors (intrusion, information attack, etc.) and predict the consequences by the nature of the restructuring of their structure. The unification of the means for processing electrophysiological signals and their cognitive visualization will help to solve the problem of selecting pilots (operators, etc.), as well as increase the efficiency of their training.

Thus, an interdisciplinary approach to cognitive visualization of the spatiotemporal structure of information sources of different nature gives a holistic perception of the features of their functioning. This allows us to identify the relationship between dynamic and statistical patterns, as well as to achieve a balance of probabilistic and deterministic research methods.

## Conclusions

In difficult conditions of functioning of dynamic systems, the key problems of analyzing digitized information flows are: a) manifestation of the individuality of the functioning of relevant information sources (sensors, biosensors, etc.); b) not the effectiveness of methods for selecting relevant information sources; c) the manifestation of cognitive distortions in the system analysis of a large amount of poorly formalized data. The unification of cognitive visualization sources of information of different nature simplifies the solution of these and other problems. The integration of digital technologies within the framework of the developed approach allows: a) to predict the vulnerability of internal information sources of a dynamic system, b) to carry out on-line identification of information sources, c) to solve the problem of effective selection of information sources, as well as pilots (dispatchers, etc.). Creating a knowledge base of typical patterns of natural sources of information and their classification will allow online identification of the functional state of the elements of complex dynamic systems. The cognitive visualization of the dynamic structure of information flows of a different nature expands the possibilities of cognition and will contribute to the increase in the efficiency of human-machine interaction.

## References


1 Ranjana K. Mehta and Raja Parasuraman, "Neuroergonomics: A Review of Applications to Physical and Cognitive Work," *Frontiers in Human Neuroscience* 7 (2013), Article 889, https://doi.org/10.3389/fnhum.2013.00889.

2 Leonid Faynzilberg, *Informatsionnyie tehnologii obrabotki signalov slozhnoy formyi. Teoriya i praktika* (Kyiv: Naukova dumka, 2008). – in Russian.

3 John K. Gilbert, ed., *Visualization in Science Education* (Dordrecht, The Netherlands: Springer, 2005).

4 Norbert Wiener, *Kibernetika, ili upravlenie i svyaz v jivotnom i mashine* [*Cybernetics: Or Control and Communication in the Animal and the Machine*] (Moscow: Nauka, 1983). – translation into Russian.

5 German Haken, *Printsipyi rabotyi golovnogo mozga. Makroskopicheskiy podhod k aktivnosti mozga, povedeniyu i kognitivnoy deyatelnosti* (Moscow: Per Se, 2001). – translation into Russian.

6 Valeriy Mygal, Andrii But, Galyna Mygal, and I. Klimenko, "An Interdisciplinary Approach to Study Individuality in Biological and Physical Systems Functioning," *Scientific Reports* 6 (2016): 387–391, https://doi.org/10.1038/srep29512.

7 Norman Packard, J. Crutchfield, J. Farmer, and R. Shaw, "Geometry from a Time Series," *Physical Review Letters* 45, no. 9 (1980): 712-716.

8 Floris Takens, "Distinguishing Deterministic and Random Systems," in *Nonlinear Dynamics and Turbulence*, edited by G. Borenblatt, G. Iooss, D. Joseph (Boston: Pitman, 1985), 314-333.

9 Heinrich Rudolf Hertz, *Printsipyi mehaniki, izlojennyie v novoy svyazi* (Moscow: Academy of Sciences of the USSR, 1959). - translation into Russian.

10 Emmy Noether, "Invariantnyie variatsionnyie zadachi," in *Variatsionnyie printsipyi mehaniki [The Variational Principles of Mechanics]* (Moscow: *Fizmatlit*, 1959), 613-614. – in Russian.

11 Valeriy Mygal, Andrii But, A. Phomin, and I. Klimenko, "Geometrization of the Dynamic Structure of the Transient Photoresponse from Zinc Chalcogenides," *Semiconductors* 49 (2015): 634–637. DOI: 10.1134/S1063782615050152.

12 Andrii But, Valeriy Mygal, and A. Phomin, "Structure of a Time Variable Photoresponse from Semiconductor Sensors," *Technical Physics* 57 (2012): 575–577.

[13] Valeriy Mygal, Andrii But, A. Phomin, and I. Klimenko, "Hereditary Functional Individuality of Semiconductor Sensors," *Functional Materials* 22, no. 3 (2015): 387–391, https://doi.org/10.15407/fm22.03.387.

[14] Keith Andrew, "Entropy," *American Journal of Physics* 52 (1984): 492–496.

[15] Valeriy Mygal, I. Klimenko, and Galyna Mygal, "Influence of radiation heat transfer dynamics on crystal growth," *Functional Materials* 25, no. 3 (2018): 574-580, https://doi.org/10.15407/fm25.03.574.

[16] Gregory B. Newby, "The Strong Cognitive Stance as a Conceptual Basis for the Role of Information in Informatics and Information System Design. Cognitive space and information space," *NY: Journal of the American Society for Information Science and Technology archive* 52, Ino. 12 (2001): 1026-1048.

[17] Toni Byuzen, *Supermyishlenie* (OOO "Popurri," 2013) [In Russian].

[18] Valeriy Mygal and Galyna Mygal, "Interdisciplinary approach to informational teaching environment formation," *Odes'kyi Politechnichnyi Universytet. Pratsi* 1, no. 54 (2018): 92-98, https://doi.org/10.15276/opu.1.54.2018.1.

[19] Valeriy Mygal and Galyna Mygal, "Method of Electrocardiographic Data Evaluation for Diagnostic Purposes," *Ukrainian patent* № 77203 (2006).

[20] Valeriy Mygal and Galyna Mygal "Cyberphysical Approach to the Study of the Functioning of Dynamic Systems," *Elektrotehnicheskie i kompyuternyie sistemyi* 22, no. 9 (2016): 354–358.

## About the Authors

Valeriy **Mygal** is Doctor of technical sciences and professor in the Department of Physics in the National Aerospace University "Kharkiv Aviation Institute," Ukraine. https://orcid.org/0000-0003-3622-5423.

Galyna **Mygal** is Doctor of technical sciences and professor in the Department of Automobile and Transport Infrastructure, National Aerospace University "Kharkiv Aviation Institute," https://orcid.org/0000-0002-9862-9338.