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Research Article

Problems of Safety in the Evolving Industrial Environment and the Development of Information Technology: The Human Factor

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ABSTRACT:

To overcome interdisciplinary barriers in solving the problems of the human factor in science, education, and technology, it is necessary to harmonize human-computer interaction. The identification of three key problems of the human factor—interdisciplinary barriers, cognitive distortions, psychophysiological compatibility—allowed us to reveal the hidden relationships between them. Systemic problems lie at the intersection of ergonomics, engineering psychology, neuro and cognitive sciences, etc. Here we show that the existing standards, approaches, and methods for ensuring biological, informational and functional safety in human factors engineering and engineering psychology are associated with the duality of perception, the individuality of thinking, and functional asymmetry of the cerebral hemispheres. They determine complex-systemic thinking and cognitive individuality associated with an intuitive search for a spatio-temporal balance between extremes. This balance depends on the functional and mental state of a person, as well as on the aesthetic perception of the digital world. Visualization of hidden spatio-temporal features of information flows of various nature in the cognitive space demonstrates the advantages and validity of a transdisciplinary approach to relevant problems of ergonomics and the human factor. The innovative potential of harmonization through a convergent approach is considered.

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Introduction

Digitalization has created a complex and amazing world dominated by uncertainty, non-linearity, and multivariance. Therefore, this world has become inaccessible in its entirety, and increasing complexity has begun to hold back the development of artificial intelligence and cognitive computing. In the new reality, information technology (IT) and information and computer technology (ICT), as well as science and education, have become the main operating factor of safety (information, functional and technological). On the one hand, IT and ICT create complex objects of an evolving industrial environment and new technologies (genetic engineering, virology, nanopharmacology, etc.). On the other hand, the phenomenon of the human factor (HF) is increasingly manifested in man-made and environmental disasters.

The processes of integration of a person with artificial environments of life activity take place at all levels of his psychophysiological and social organization. Plunging into the artificial environment created by digital technologies, a person actively interacts with it. It is also a catalyst for the increasing complexity that has come to limit the development of IT and ICT. As a result, new systemic problems have increased the number of man-made and environmental disasters.

The human factor in ensuring safety. The existing standards, approaches and methods for ensuring biological, informational and functional safety in human factors engineering and engineering psychology have created new contradictions. They are due to the duality of perception, the individuality of thinking and the functional asymmetry of the cerebral hemispheres, which determine complex systemic thinking. Therefore, the operator (dispatcher, etc.) has to make decisions in extreme conditions (limited time, redundancy or insufficiency of information, etc.), in which the cognitive aspects of human-computer interaction are manifested. The human factor requires the development of ergonomic research methods on a transdisciplinary basis.

Potential to use the results of the study. The digitalization of ergonomic research methods on a transdisciplinary basis has a high innovative potential. In particular, such digitalization allows to carry out:

- professional diagnostics of functional states (FS) online;
- psychological research in the selection of operators and their admission to work online;
- identification of transitional functional states, which are caused by environmental and activity stress factors.

The purpose of the work is the harmonization of human-computer interaction through digital complementary ergonomic research methods.

This article is organized as follows. Section 1 defines the cognitive aspects of the increasing complexity of human-computer interaction, as well as the problems of cognitive perception of the increasing dynamic and statistical complexity are considered. They, in turn, create systemic problems of information (func-

tional and energy) safety that cannot be solved within the framework of an interdisciplinary approach. To solve them, we have identified three key problems in modern ergonomics/HF, which are created by digitalization: interdisciplinary barriers, hidden cognitive distortions, unpredictability of activities under the influence of stress factors. These are systemic problems, the hidden connections of which are a consequence of:

- the downside of automation and increasing complexity;
- transient psycho-physiological and mental states induced by environmental stress factors and activities;
- manifestations of the law of perception of information "seven plus minus two," which reflects the impact of extreme conditions on activities.

To harmonize human-computer interaction in extreme conditions, we have expanded ergonomic research methods through the natural circle of Goethe colors and fractal logic.

In section 2 "Problems of safety and the increasing complexity of their solution" we discuss the transdisciplinarity of safety problems. The unpredictability of cognitive distortions (systematic errors) under extreme conditions is researched by neurosciences and cognitive sciences. It has been established that cognitive distortions are generated by an increasing number of information sources, their excessive formalization and induced feedback asymmetry. The consequence of this is new interdisciplinary problems that manifest themselves in extreme conditions in the form of the phenomenon of the human factor. It is shown that the selection of explicit relationships in sources of information of various nature and media of its transmission by primary colors, and induced (implicit) relationships by colors of the first order contribute to solving security problems through intuition, the development of which determines the successful experience of solving problems.

Section 3 "Spatio-temporal features of interaction as a source of information" draws attention to the hidden relationships of dynamic and statistical complexity. These interrelations are sources of qualitatively new information about the imbalance of conjugated components of information flows of various nature, as well as about the symmetry / asymmetry of their dynamic structure. The visualization of these features in the cognitive space of dynamic events increases the innovative potential of digital research methods in ergonomics / HF. The conclusions show that the transition from multidisciplinarity to transdisciplinarity opens up new opportunities for harmonizing human-computer interaction in solving problems of information (functional and biological safety).

Cognitive Aspects of the Increasing Complexity of Human-Computer Interaction

Problems of cognitive perception of information sources of various nature

New problematic fields (phenomena, effects) require their understanding not only within the boundaries of their own space. The complexity of modeling, research and diagnostics of the functioning of information sources of various nature (sensors, detectors, intelligent materials, and others) is due to their non-linearity, uncertainty and ambiguity (non-linearity, uncertainty, ambiguity). They, as shown in papers,[1, 2] are connected with Gödel's theorem,[3] which is in the foundations of metamathematics. Its application in the neurosciences (neural networks, neuroergonomics, etc.),[4, 5] as well as in the life sciences (information biology, engineering psychology, etc.) made it possible to establish that:

- nonlinear effects in complex dynamic systems (CDS) are described by appropriate physical and biological models;
- the future of the CDS determines the behavior of the nonlinear system in the present;
- instability of the CDS element with a small external influence can determine its further evolution.

Therefore, each functional state of the CDS element, including the operator, has informational and biological components, the interaction of which determines its individuality. As a result, the non-linearity, uncertainty and ambiguity of the functioning of the CDS elements increases the number of manifestations of the human factor phenomenon in man-made, environmental and other disasters.

The variety of means for processing, visualizing and analyzing information has increased the complexity of information, which has led to the manifestation of cognitive aspects in the management of complex dynamic systems in extreme conditions.[6] The consequence is the increasing complexity of the interrelationships of the elements of the CDS, including the person, on the consistency of which the complexity of thinking depends. The difference in the complexity of the functioning of the CDS and processes (information flows, etc.) increases the complexity of decision making

Cognitive Dualism

Cognitive problems. The use of neurosciences (neuroergonomics, neuropsychology, etc.) made it possible to establish that cognitive problems depend on the psychophysiological state of a person. Therefore, the study of activities in the digital world limits many problems. The key problems for cognitive perception are:

- presentation and analysis of little formalized information;
- studying the features of thinking and identifying cognitive distortions,
- diversity and multiscale of information sources.

They give rise to contradictions between the style of thinking and the methods of processing, displaying and analyzing information. All problems are related to the complexity of discrete thinking, which is based on intuition.

Duality of perception of nature, individuality of thinking and functional asymmetry of the cerebral hemispheres determine the features of cognitive activity.[7, 8]

Psychological space and time is connected with microspace and microtime, as indicated by the fractality of cyclic electrophysiological signals. This confirms the effectiveness of the use of the fractal triangle in heuristic and cognitive modeling.[9] Therefore, cognitive problems are closely related to the intuitive search for a spatio-temporal balance between extremes.

Distortion of information. The degree of information distortion under external and internal influences depends on the psycho-physiological state of a person, which psychologists determine using conflicting color tests. This is due to the unreasonable choice of four primary colors (blue, red, yellow and green). Whereas Goethe's circle of natural colors includes primary colors (blue, red and yellow) in the form of a triangle, and first-order colors in the form of an inverted triangle (violet, orange and green), and harmonization is achieved through the balance of conjugate components and the contrast of opposites. Note that I. Goethe developed the theory of the circle of natural colors for 40 years and considered it his greatest achievement.[10] To harmonize human-computer interaction, we highlighted the explicit and hidden interconnections of the elements of the CDS, including the operator (dispatcher, etc.), which cause cognitive distortions and spatio-temporal features (Fig. 1).

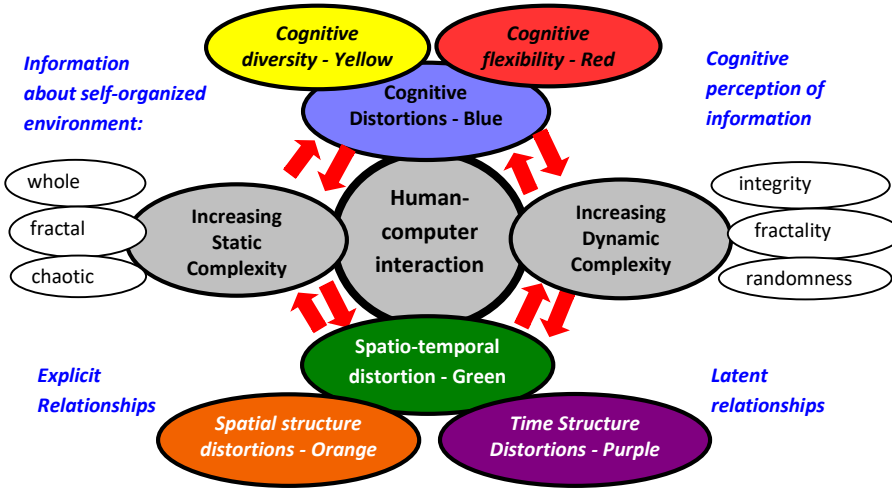

Figure 1: Explicit and implicit relationships of increasing static and dynamic complexity.

It is important that highlighting natural relationships in information sources with primary colors (blue, yellow and red) and induced relationships with secondary colors (green, orange and purple) encourages the use of intuition. As can be seen from the figure, a combination of harmonious colors located nearby strengthens them, and a combination of less harmonious colors leads to disharmony. Therefore, their analysis simplifies the identification of the features of human-computer interaction in extreme conditions.

Sources of information distortions. Stress factors of the environment and activities cause spatial and temporal distortions of the information flow. They are associated with local inhomogeneities of information sources of various nature (sensors, detectors, etc.), as well as with local inhomogeneities of transmission channels.[6] All this, when exchanging information, significantly affects the network topology (physical, logical and informational). However, within the framework of a transdisciplinary approach, they can be universal sources of information, from which, using the measured time series (scalar signal), one can reconstruct a topological 3D model.[11]

New knowledge based on successful experience and visualization. Causal relationships of cognitive aspects with different types of complexity are considered in the works of Mygal V. at al., 2020-2022. They show that cognitive distortions are the result of individual perception and representation of complexity, instability and non-linearity. Changing the dynamic structure of the hidden relationships of the information flow determines the functionality of the information source. Therefore, cognitive distortions create many problems that are caused by an increase in the induced complexity of conjugated relationships.[2, 6] The key issues are:

- selection of relevant sources of information;
- selection of controllers (operators, pilots, etc.) online, as well as sensors of various nature;
- monitoring the functional state of operators online.

Desynchronization of information flows leads to an increase in the complexity of their analysis and the uncertainty of its results. Therefore, the solution of these problems in the multidisciplinary cognitive space has not been achieved. The distortion of the structure of information flows of various nature in transmission lines, as well as in systems for processing, presenting, and analyzing information associated with the Le Chatelier principle.[12] Spatial heterogeneities induce temporal heterogeneities that create latent cognitive distortions. Interdisciplinary difficulties and problems of sciences and technologies limit the possibilities of their visualization and, as a result, study and forecasting.

Safety Problems and the Increasing Complexity of Their Solution

Transdisciplinarity of Safety Problems

The relationship of knowledge and control. The digitalization of education has created new problems that are directly related to the processes of management

and cognition. These processes include the collection of information, its transmission, accumulation and processing. The use of this information in the process of developing control actions considers the dual unity of the processes of control and cognition, which are based on active reflection and cyclicity. To predict safety (biological, physical, functional and informational) in unforeseen conditions, a convergent approach and tools on a transdisciplinary basis are needed. The development of critical thinking and intuition in the process of education and professional activity will help maintain human resilience.[13]

To do this, it is necessary to establish the causes of explicit and hidden cognitive distortions that lie at the intersection of ergonomics, engineering psychology, neurosciences and cognitive sciences. Their causes are associated with information overload when exposed to environmental and activity stress factors. Cognitive distortions are generated by an increasing number of information sources, their excessive formalization and induced feedback asymmetry.

Human in extreme conditions. The conducted research allowed to establish that the problems of human functioning in extreme conditions are associated with the manifestation of the fundamental principle of Le Chatelier-Brown. These problems arose at the intersection of ergonomics, engineering psychology, neurosciences and cognitive sciences. They are generated by digitalization and for their solution we will single out three key problems:

- Erasing the boundary between truth and falsehood removes fluctuations, and they are a new source of hidden information in the cognitive space of dynamic events;
- Accounting for the connection of formalized regularities (physical and mathematical models) with extreme principles of natural science;
- Induced asymmetry of color perception of information sources of different nature and medium of its transmission, which depends on the psycho-physiological state of the operator.[9, 14]

It is known that R. Feynman's hypothesis interprets the change in microprocesses of the main topological property - the linear ordering of time, which appeared during the reconstruction of natural fractal signals in the space of dynamic events.[14]

Information overload. The concept of complexity is interdisciplinary and inherent in all dynamic systems. Different types of complexity were developed by S. Beer, N. Wiener, I. Prigozhin, and G. Haken.[7, 8, 15-17] All types of complexity are manifested in thinking in complexity.[18] Features of thinking depend on information overload and the psychophysiological state of a person. It is obvious that the consequence of the multidimensionality of the concept of complexity is the phenomenon of the human factor. After all, one of its main reasons is the dynamic complexity of processes (phenomena), which is due to time delays in the interaction due to increasing complexity.

A variety of relevant sources of information and an increase in their number leads to information overload (impairment of memory, concentration, etc.),

which negatively affects the decisions made. The dynamic complexity of information sources and information transmission lines is generated by the impact of stress factors that increase structural complexity and, accordingly, cognitive load. In human-computer interaction, such a load leads to cognitive diversity and cognitive distortions.[6, 13] They create risks in the management of the CDS and influence the decisions made.

Spatio-temporal Features of Interaction as a Source of New Information

Hidden Cognitive Distortions

Related components of information sources and elements of the CDS. Cognitive distortions are due to the imbalance of the conjugated components of the CDS, including the person, as well as the symmetry / asymmetry of their dynamic structure. Distortions of information under external and internal influences affect the transitional psycho-physiological states of a person.[1] Causal relationships of cognitive aspects with different types of complexity are considered in the works.[14, 6] They show that cognitive distortions are the result of individual perception and representation of complexity, instability and non-linearity. Changing the dynamic structure of the hidden relationships of the information flow determines the functionality of the information source. Therefore, cognitive distortions create difficulties, problems and contradictions, which are caused by an increase in induced complexity (Mygal V. at al., 2020-2022). The key ones are:

- difficulties in selecting relevant sources of information;
- problems of identifying hidden cognitive distortions for the effective selection of operators (pilots, etc.) resistant to stress, as well as their admission to work;
- contradictions in the understanding of the same terms in different subject areas.

They also cause desynchronization of information flows, which leads to an increase in their complexity and uncertainty. The solution of these problems in the multidisciplinary cognitive space has not been achieved, and further differentiation of sciences only increases the manifestation of the phenomenon of the human factor.

Structural and balance changes. In the our works [19] it is shown that local distortion of the structure of information flows of various nature in transmission lines, as well as in systems for processing, presenting and analyzing information is associated with the structural features of dynamic and statistical links. There are interrelations between the features of dynamic and statistical complexity, which, under extreme conditions, change their structure. This gives rise to hidden cognitive distortions (systematic errors). At the same time, visualization of changes in the structure of dynamic features with primary colors (blue, yellow and red), and statistical features with auxiliary colors (green, orange, purple) allows you to analyze changes in the symmetry / asymmetry of the structure, as

well as the balance of their conjugate components. This includes intuition for uncovering hidden relationships (see Figure 2).

As can be seen from Figure 2, a combination of harmonious colors located side by side strengthens them, and a combination of less harmonious colors leads to disharmony. The application of thermodynamic principles and criteria creates new opportunities for the development of intuition, which is associated with successful experience in solving real problems.

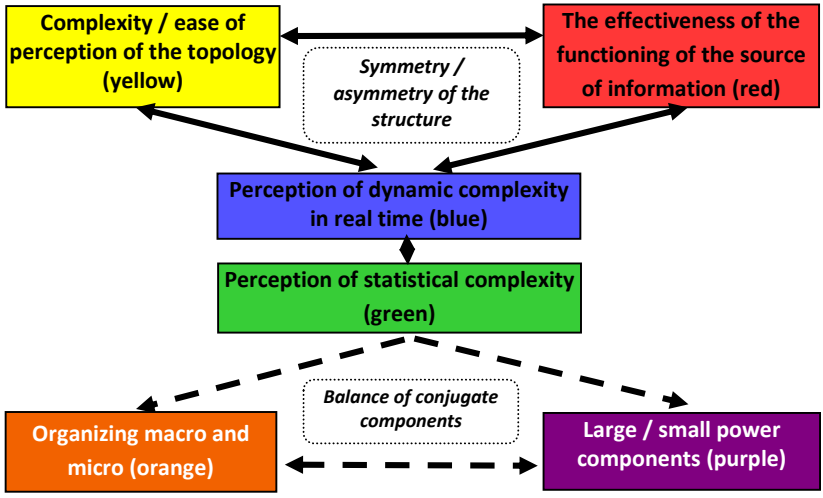

Figure 2: Relationships between dynamic and statistical complexity.

Individual features of logic and intuition. Logical thinking is only a tool of proof, but not an invention, and therefore does not create anything new (A. Poincaré).[20] In our opinion, heuristic activity includes both logic and intuition, which is based on individual successful experience and biomimicry.[21] Logic and intuition are the two components of heuristic activity, which is aimed at discovery, invention and know-how. Therefore, digital modeling is based on modern metaphysics,[22, 23] and in heuristic modeling, a triad of complementary principles is important.[9]

Key features of the functioning of information sources and features of thinking in complexity. The discrepancy between the complexity of thinking and the complexity of the sources of information about the functioning of the CDS limits the possibilities of management. After all, despite the further growth of computational capabilities, there is an asymmetry of relationships between the formalized features of the functioning of the elements of the CDS and the individual characteristics of thinking. Therefore, the complexity of the dynamic structure of information flows of various nature limits the possibilities of predictive analytics, modeling, data mining, etc.

Innovative potential. The innovative potential for the development of digital research methods in ergonomics/HF is based on a convergent approach and tools on a transdisciplinary basis. In particular, the number of natural honeycomb structures is two to three orders of magnitude greater than that of artificial models. Their connection with the natural harmony of colors in nature "turns on" emotional intelligence, creating new opportunities for solving relevant problems in digital ergonomics / HF. In particular, the application of the fractal triangle and fractal logic has a high cognitive value.[9]

Parametric signal geometrization. The development of the idea of parametric 3D geometrization of an information flow of various nature (signal) made it possible to develop a metaphysical approach to the analysis of the functioning of dynamic systems and tools for its implementation.[13, 19] The approach is aimed at resolving the main contradiction of ergonomic studies, namely between their systemic methodology and a variety of unrelated means of systemic research. Therefore, the core of the approach is the natural geometrization of the signal dynamics of the information source and the medium of their transmission. This is implemented in the space of dynamic events (state – speed – acceleration), where signals of various nature are transformed into a closed trajectory of dynamic events I.[20] Orthogonal projections of a parametric 3D trajectory are signatures of the 1st and 2nd order, i.e. natural individual graphic images of the signal (see Fig. 3).

The universal parameters of the dynamic structure of the signal are: differential-geometric parameters of signature configurations (the length of the ordered sections-components ΔX, their steepness dX/dt or curvature d^2X/dt^2); linear density of states Δn/ΔX; dynamic parameters of conjugate components of the signal structure.

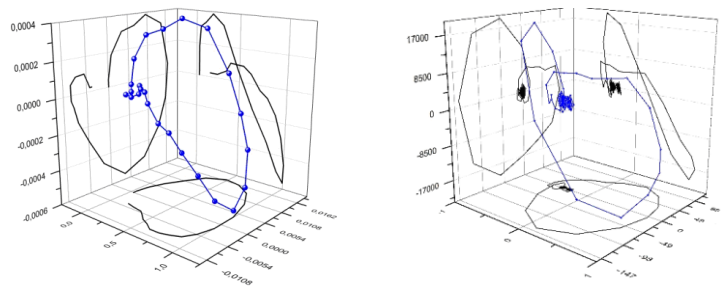

Figure 3: Cognitive graphic images of a semiconductor sensor and human ECG.

Statistical performance indicators are: - powers of subsets of allowed states; Boltzmann entropy H=k·lnW, which is a universal characteristic of the orderliness of processes and signals of different nature; entropy production rate dH(t)/dt; indicators of dynamic balance (the ratio of the areas of the upper S_v and lower S_n parts of the signature, i.e. $V_{din} = S_v/S_n$). To reveal the statistical regularities of the restructuring of the structure, the signal cycles are not averaged,

but the nature of the change in the area of signatures in the packet is considered. At the same time, the analysis of the nature of the restructuring of cognitive graphic images in the package allows you to identify the transitional states of a person or sensors (detectors, etc.). The discrepancy between the complexity of thinking and the complexity of the sources of information about the functioning of the CDS limits the possibilities of management. After all, despite the further growth of computational capabilities, there is an asymmetry of relationships between the formalized features of the functioning of the elements of the CDS and the individual characteristics of thinking. Therefore, the complexity of the dynamic structure of information flows of various nature limits the possibilities of predictive analytics, modeling, data mining, etc.

Conclusions

The growth of complexity and automation in systems, the need for decision-making in extreme conditions (limited time, redundancy or insufficiency of information) increases the cost of erroneous human actions. This has led to a significant increase in the complexity of the study of evolving self-organized media. A systematic analysis of human operator errors, accidents and disasters shows that interdisciplinary safety problems cannot be resolved within the framework of existing approaches to human factor engineering and engineering psychology.

A characteristic feature of human activity in the performance of training, dispatching, technological, management functions is the unpredictable occurrence of problematic (complex, emergency, emergency) situations. Due to fatigue or the impact of extreme stress factors of various origins (environmental, informational, etc.) on the functional state of a person, an important role is played by the individual nature of changes in the dynamics of his physiological and psychological processes. Therefore, the unique possibilities of harmonizing human-computer interaction to solve security problems online are essential in extreme conditions.

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