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NON-STATIONARY STATES IN PHYSICS AND BIOPHYSICS

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Abstract: I. R. Prigogine emphasized the need to research unstable systems. However, for the last 40 years, this problem has not been studied well. Still, in the last 25 years, the statistical instability of biomechanical motion properties was proved as the Eskov–Zinchenko effect. Such unstable systems exist in the Earth's inorganic nature, too, as the human habitat climate/weather regulation systems. In 1948 W. Weather called such systems "3rd kind systems". They feature a special statistical instability peculiar to self-organizing systems. The study presents the key properties of such 3rd kind systems and some invariants that define these non-stationary systems. Significantly, the simulation is based on some quantum mechanics postulates. Particularly, these are the Heisenberg uncertainty principle, and the quantum entanglement principle.

Keywords: non-stationary state, 3rd kind systems, Eskov-Zinchenko effect, quantum entanglement.

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ПРОБЛЕМА НЕСТАЦИОНАРНОСТИ В ФИЗИКЕ И БИОФИЗИКЕ

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Аннотация: необходимость изучения неустойчивых систем подчеркивал I. R. Prigogine, но за последние 40 лет эта проблема не рассматривается в науке. Однако за последние 25 лет была доказана статистическая неустойчивость параметров движения в биомеханике в виде эффекта Еськова–Зинченко. Подобные неустойчивые системы имеются и в неживой природе на Земле в виде систем регуляции климата и метеопараметров среды обитания человека. Эти системы в 1948 г. W. Weaver обозначил как системы третьего типа, они обладают особой статистической неустойчивостью, характерной для самоорганизующихся систем. В работе представлены основные свойства таких систем третьего типа и некоторые инварианты для их описания. Существенно, что их моделирование основано на ряде принципов квантовой механики. В частности, принципе неопределенности Гейзенберга и квантовой запутанности.

Ключевые слова: нестационарность, системы третьего типа, эффект Еськова–Зинченко, квантовая запутанность.

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Соблюдение этических стандартов: все процедуры, выполненные в исследовании с участием людей, соответствуют этическим стандартам институционального и/или национального комитета по исследовательской этике, Хельсинкской декларации 1964 года и ее последующим изменениям или сопоставимым нормам этики.

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Introduction

In 1989, I. R. Prigogine [1] for the first time in the history of science drew attention to the lack of proper attention in modern science to unstable systems. There is no developed theory for them, and there are no models to describe such systems. By now enough experimental data have already been accumulated that allow us to present some classification of such unstable systems and to build some theoretical models for their description.

Let us recall that W. Weaver [2] more than 70 years ago presented a special classification of all systems in nature. In our interpretation, we are talking about deterministic systems (*simplicity systems* – type 1), stochastic systems (*nonorganized complexity* – type 2) and systems of the third type (3TS) – *organized complexity*. The first two types of systems are the object of study of modern science, but nothing has been created for 3TS during these more than 70 years. W. Weaver primarily classified living systems as 3TS, but what special properties do such systems have and why can they not be the object of study in functional analysis and stochastics? These questions were not answered by W. Weaver or two Nobel laureates (I. R Prigogine [1, 3], M. Gell-Mann [4]).

To answer these questions we need to present special properties of 3TS and propose a formal apparatus for their description, which can be based on several principles of quantum mechanics [5-7]. Let us emphasize that we are not talking about dynamic chaos, but about a special type of unstable systems. These are systems with statistical instability of any parameters $x_i(t)$ that form the system state vector $x=x(t)=(x_1, x_2, \dots, x_m)^T$ in the m-dimensional phase space of states (PSS) [3-5]. The dynamics of 3TS-complexity behavior cannot be described within the framework of modern science.

The general problem of nonstationarity

There are a huge number of objects (systems) in the animate and inanimate nature that exhibit nonstationary behavior. For example, in 2009 the star KIC 8462852 (star Tabby) was discovered, which showed a particular irregularity both in luminosity and in the intervals (periods of oscillation) of this luminosity. In 2007, fast radio bursts (FRBs) were recorded, which also showed the absence of any periodicity in their characteristics. There are also many objects on the Earth, which show a particular instability. It is manifested in the absence of statistical stability of samples of the state vector of the system $x=x(t)=(x_1, x_2, \dots, x_m)^T$ in the PSS [3, 4, 6–8].

In 1989, I. R. Prigogine [1] emphasized (see Philosophy of instability) the necessity to study such unstable systems, but no progress in this field has been established over these 30 years. The very notion of ”instability” requires a clear mathematical definition, which as of today does not exist, or rather there is no classification of the types of instability. The generally accepted definition of the stationary mode (SM) for any dynamical system (in a deterministic approach), for the state vector of the dynamical system $x(t)$ in PSS as $dx/dt=0$ and $x_i=const$, has very limited application in the study of 3TS [6–8]. It concerns systems that are described within the framework of functional analysis, and let us say at once that all living systems (STT, by the definition of W. Weaver [2]) are not dynamic systems (in the sense of determinism), i.e. for them $dx/dt\neq 0$ is continuous (and constant) [8].

In stochastics, there is a notion of statistical stability (invariance), when during multiple repetitions of a process in observation of many samples of the same variable $x_i(t)$ we will observe invariance of statistical distribution functions *f(x)*, their statistical characteristics (statistical mean $< x >$, statistical dispersion (D_x^*), spectral signal densities (SSD), autocorrelations *A(t)*, etc.) If *f(x)*, SSD, *A(t)* and other characteristics do not change from sample to sample, then in stochasticity we conclude that the system is invariant [3–5].

However, in living and inanimate nature some systems cannot be repeated not only at the end of the process (as samples of the final state of the system $x_i(t_k)$), but also as the initial parameters of the vector $x(t_0)$. In this case, any dynamical equation is unique because the next repetition of the dynamics of the process leads to other equations [3–5]. This means that there is no Cauchy problem, no causality, and no predictability of not only $x(t_k)$ but also of any samples of the final state $x(t_k)$ [6–8]. These are precisely the properties of living systems.

Such systems continuously show $dx/dt \neq 0$, and their statistical functions *f(x)*, SSD, *A(t)*, and other characteristics cannot be repeated twice in a row arbitrarily [3–9]. These are statistically unstable systems with some self-organization. They cannot be described within the framework of functional analysis (determinism) or stochasticity. For them, it is necessary to create a new theory and new models. Such work requires, first of all, the development of new invariants for the estimation of stationary states (and a new understanding of such stationary modes: SMs) and the estimation of kinematics *x(t)* in PSS [3–5, 8]. Some authors [9–12] also note the instability in the brain neural networks, which is approaching the chaos of 3TS [3–5].

Statistical Parameter Instability in Biomechanics and Meteorology

Earlier [3–5] we noted that in biomechanics, any movement has a unique character [13]. This means that the matrix of pairwise comparisons of samples of tremorograms (TMG) or teppingrams (TPG) demonstrates an extremely small share of stochasticity (for TMG less than 5%), i.e., we observe statistical chaos for samples of TMG. Our further studies showed that a similar result (low stochasticity fraction) is observed for spectral signal densities (SSD) as TMG, or TPG, or human SSS parameters [14–15]. For example, in Table 1 we present a matrix of pairwise comparisons of SSD that were obtained by fast Fourier transform from 15 TMGs (from the same subject in his unchanged state) [3–5].

Table 1

Matrix of paired comparison of 15 SSD tremorograms of one GDS subject in repeated experiments ($k_1 = 25$), by Wilcoxon criterion

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1		,00	**,95**	,01	,00	**,13**	**,77**	,00	,00	,00	,00	,02	**,68**	,00	**,58**
2	,00		,00	,00	,00	,00	,00	,00	,00	**,08**	**,90**	,00	,00	,00	,00
3	,95	,00		,01	,00	**,15**	**,56**	,00	,00	,01	,00	**,48**	**,38**	,00	**,60**
4	,01	,00	,01		,00	,00	**,07**	,00	,00	,00	,00	,00	,01	,00	,01
5	,00	,00	,00	,00		,00	,00	**,11**	**,74**	,00	,00	,00	,00	,00	,00
6	,13	,00	,15	,00	,00		**,17**	,00	,00	,02	,00	**,60**	**,13**	,00	**,29**
7	,77	,00	,56	,07	,00	,17		,00	,00	,01	,00	,01	**,66**	,00	**,75**
8	,00	,00	,00	,00	,11	,00	,00		,00	,00	,00	,00	,00	,00	,00
9	,00	,00	,00	,00	,74	,00	,00	,00		,00	,00	,00	,00	,00	,00
10	,00	,08	,01	,00	,00	,02	,01	,00	,00		,02	**,06**	,00	,00	,00
11	,00	,90	,00	,00	,00	,00	,00	,00	,00	,02		,00	,00	,00	,00
12	,02	,00	,48	,00	,00	,60	,01	,00	,00	,06	,00		**,12**	,00	**,17**
13	,68	,00	,38	,01	,00	,13	,66	,00	,00	,00	,00	,12		,00	**,54**
14	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00		,00
15	,58	,00	,60	,01	,00	,29	,75	,00	,00	,00	,00	,17	,54	,00	

Several hundred such matrices were constructed for the TMG and TPG samples themselves of their SSD and *A(t)* for more than 100 subjects, and in all cases, we had a stochasticity fraction of less than 25%. This means that the number of k_1 SSD pairs that have a Wilcoxon criterion of $p \geq 0.05$ is small. There is no statistical robustness of samples not only of TMG or TPG, but also of their SSD, *A(t)*, and other statistical characteristics. Any sample in biomechanics will be unique (statistically unique). The statistics will then have a historical character (no predictions). Characteristically, this is now designated as the Eskov-Zinchenko effect (EZE) and this EZE is extended to many other body parameters [7, 8, 13].

We emphasize that 3TS include not only living systems but also many climate parameters and meteorological parameters [3, 4]. As an example, we present Table 2 for air temperature (for 15 years, samples for January). This table presents the results of statistical comparison of pairs of samples of air temperature parameters T for 15 January in the Khanty-Mansi Autonomous Okrug – Ugra (for 15 years). The number of temperature sample pairs k, for which the Wilcoxon criterion $p \geq 0.05$ (i.e., the two temperature samples being compared may have one common general population) is small: k_2=30.

Table 2

Matrix of pairwise comparison of samples of temperature T for January 1991–2009, Wilcoxon criterion was used (significance level $p < 0.05$, number of coincidences $k_2 = 30$)

	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
1991		,00	,00	,00	,00	,00	,00	,00	,00	,00	**,62**	,00	,00	,00	,00
1992	,00		,03	,01	**,38**	**,50**	,00	**,98**	**,22**	**,15**	,00	,00	,00	**,80**	**,97**
1993	,00	,03		,00	,05	,00	**,37**	,02	,00	,00	,00	,00	,00	,00	,00
1994	,00	,01	,00		**,11**	,01	,00	,00	**,20**	**,06**	,04	,00	,00	,00	,00
1995	,00	,38	,05	,11		**,71**	,01	**,66**	**,12**	**,59**	,00	,00	,00	**,76**	**,63**
1996	,00	,50	,00	,01	,71		,00	**,37**	**,98**	**,62**	,01	,00	,00	**,51**	**,32**
1997	,00	,00	,37	,00	,01	,00		,01	,00	,00	,00	,00	,00	,00	,00
1998	,00	,98	,02	,00	,66	,37	,01		**,23**	,05	,00	,00	,00	**,56**	**,67**
1999	,00	,22	,00	,20	,12	,98	,00	,23		**,94**	,00	,00	,00	**,40**	**,08**
2000	,00	,15	,00	,06	,59	,62	,00	,05	,94		,00	,00	,00	,01	,05
2001	,62	,00	,00	,04	,00	,01	,00	,00	,00	,00		,00	,00	,00	,00
2002	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00		,00	,00	,00
2003	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00	,00		,00	,00
2004	,00	,80	,00	,00	,76	,51	,00	,56	,40	,01	,00	,00	,00		**,97**
2005	,00	,97	,00	,00	,63	,32	,00	,67	,08	,05	,00	,00	,00	0,97	

Comparing characteristic tables 1 and 2 (from biomechanics and meteorology), we can make a general conclusion about the absence of statistically stable samples of tremorograms and temperatures of the human environment. In other words, we prove N.A. Bernstein's hypothesis of "repetition without repetition" not only in living nature but also in nonliving nature. For these two different systems, we have EZE, i.e. there is no statistical stability of samples xi of the process under study [3–5, 14–15]. The creation of new models and new invariants should change the situation in biophysics and cybernetics (when studying 3TS).

We now denote all such systems as homeostatic systems (HS), i.e. they exhibit statistical chaos (the stochastic fraction for TMG is less than 5%, and for T – less than 30%). How then can such processes be compared, how can the system's invariance and its real change be determined, if all statistical functions f(x), SSD, A(t), and other statistical characteristics change continuously and chaotically even in a supposedly stationary regime? For all such HS there is EZE, and then it is necessary to create new invariants and new methods of modeling stationary modes (SM) [3, 4].

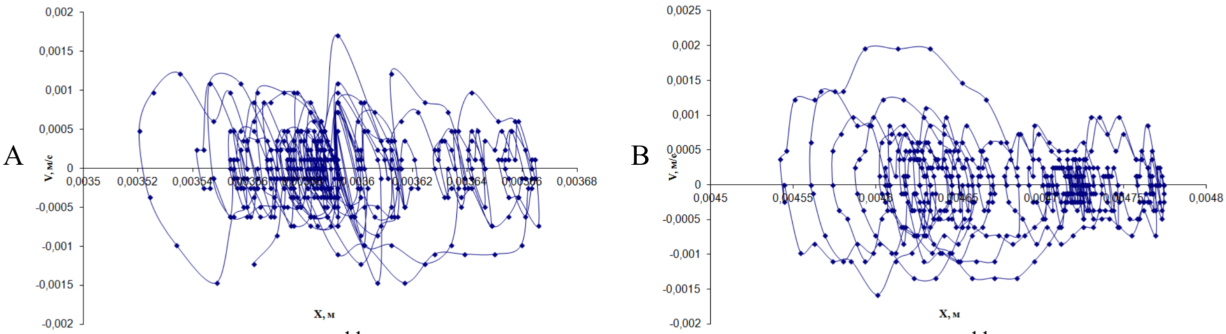
New Invariants for Homeostatic Systems

We emphasize again that modern stochastics cannot describe supposedly unchanging systems, but their statistical functions, SSD, *A(t)* will change continuously and chaotically from sample to sample. Note that if we have different objects of research, for example, we record TMG in 15 different subjects, we also get a matrix of pairwise comparison of TMG samples similar to Table 1. In this case, we can speak about the loss of homogeneity of samples. In the case of temperature we can take 15 different samples for January of a certain year, but from different geographical territories and get a table similar to Table 2.

The presence of small k_1 (low stochasticity) indicates a loss of homogeneity of the group. In other words, we can never get a homogeneous group of subjects in biomechanics or parameters in meteorology. How to work with such samples? What are stationary modes for such systems (3TS – HS) and what invariants should be taken to prove the existence of SM in such 3TS – HS? Answers to these questions follow from the analogues of quantum mechanics in the description of 3TS-*complexity* [4–6].

Let us recall that the Heisenberg uncertainty principle imposes constraints on the phase coordinates x_1 – the displacement (of a quantum particle, for example) and $x_2 = dx_1/dt$ – the speed of this displacement. It follows from the Heisenberg inequality that $\Delta x_i \cdot \Delta P \geq h/(4\pi)$, where $P = x_2 \cdot m$. If (at low velocities) the mass m of the particle is constant, we have the Heisenberg equation only for the phase coordinates: $\Delta x_1 \cdot \Delta x_2 \geq h/(4\pi m) = Z^k{}_{min}$.

In the case of biomechanics, we can introduce an analogue of the Heisenberg principle in the form: $Z_{max} \geq \Delta x_1 \cdot \Delta x_2 \geq Z_{min}$, where Z_{max} and Z_{min} is some constants for a given subject in a particular state. Z_{max} and Z_{min} have nothing in common with Z_{max} and Z_{min} from quantum mechanics, but they are real constants that constrain our phase coordinates (x_1 is the finger coordinate, x_2 is the rate of change of $x_1(t)$). On the vector plane $x=x(t)=(x_1,\ x_2)^T$ in biomechanics we have some phase trajectories (see Fig.) of $x(t)$ motion, which characterize tremor (or any other human movement) in the phase space of states (PSS) [3–5].



$S_1 = 4{,}61 \cdot 10^{11}$ units $\qquad$ $S_2 = 8{,}21 \cdot 10^{11}$ units

Figure. *Phase trajectories and their PAs for the same subject: A – during relaxation; B – during loading, F=3 N*

Fig. shows the character of TMG phase trajectories of the same subject in two different physical states (finger tremor without load, F_1=0 and finger tremor with load, F_2=3 N). In two different physical states, the biomechanical system demonstrates two different phase trajectories. Moreover, each phase trajectory occurs inside a rectangle with sides Δx_1 (variation spread over x_1) and Δx_2 are the areas S_1 and S_2, within which the vector $x(t)$ moves continuously and chaotically [14–15].

The bounded region of the PSS, within which the state vector $x(t)$ of a homeostatic system moves (chaotically and continuously), we denote as the pseudo attractor (PA) (or the Eskov quasi attractor (QA)). We will present the exact definition of the PA (or QA) below, but now only note that the PA area and the coordinates of its center (see Fig. 1) are invariants. They are statistically conserved for the same GS being in an unchanged (from the position of the new chaos-self-organization theory (CSO) [3–5]) state.

When evaluating the state (in Fig. we move from PA^1 without load to PA^2 with load) of the system, we observe a change in the area S for the PA and a change in the coordinates $x^c{}_i$ of the center of the PA. Let us emphasize again that the functions $f(x)$, SSD, $A(t)$, etc., change continuously and chaotically. Let us present the definition of a PA (or Eskov's QA) in the framework of functional analysis.

Formally, the definition of a PA is as follows: PA is a nonzero subset Q of the phase m-dimensional space D l= of a dynamic biological system (3TS), which is the union of all values $f(t_i)$ of the state of the biological dynamic system at a finite time interval $[t_j, \ldots, t_e]$ ($j << e$, where t_j is the initial time moment and t_e is the finite time moment of biosystem states):

$$Q = \bigcup_{l=1}^{m} \bigcup_{i=j}^{e} f^l\,(t_i)\,, Q \neq 0;\ Q \in D, \tag{1}$$

where m is the number of coordinates of x spatial dimensions.

To illustrate the invariability (statistical stability) of samples of parameters S for PA in the case of biomechanics (TMG registration) we present Table 3. Here we present the results of calculations of area S for PA of the same subject in two different physical states: without load on the limb (F_1=0) and with load (F_2=3 N). Obviously, after 15 repeated TMG recordings in the same subject, we have significant differences between the mean $< S_1 >$=3.02 units (at F_1=0) and the mean $< S_2 >$=4.93 units (at F_2=3 N) for the same subject. The S areas for PA are statistically robust and significantly different.

In general, in the phase coordinates x_1 and $x_2 = dx_1/dt$ we have biomechanical invariants (in the form of pseudo attractor area S) for the same subject. A change in physical status (transition to F_2) leads to a

Table 3

Values of pseudoattractor areas S of samples of tremorograms of the same subject

	$S_1 \cdot 10^8$ units,off-load	$S_2 \cdot 10^8$, units, $F_2 = 3$ N load
1	5,78	3,55
2	2,29	3,87
3	1,42	5,74
4	3,89	2,92
5	1,61	6,82
6	3,03	5,71
7	3,86	3,67
8	1,69	4,77
9	1,77	6,78
10	6,27	7,24
11	1,92	5,06
12	2,02	5,28
13	3,42	2,91
14	3,98	6,24
15	2,27	3,36
<*S*>	3,02	4,93
	Wilcoxon test, significance of differences in *f(x)* functions $p = 0.01$	

change in area *S*. Let us emphasize that all statistical characteristics change chaotically and continuously when the biosystem state is unchanged (see Table 1 and Fig.).

Thus, we prove the absence of invariants for the parameters of biosystems within stochasticity (all samples *x(t)* are continuously and chaotically changing), which imposes limitations for further application of stochasticity in biomechanics and the study of electro generating biosystems [9–12]. On the other hand, new quantitative characteristics emerge that will be invariant for real (in the biological sense) stationary modes of various biosystems. All biophysics and biocybernetics now need to create a new theory and new models in the description of 3TS-*complexity*, special homeostatic systems with statistical instability of *x(t)* samples [13, 16].

Conclusion

The problem in the study of statistical stability of parameter samples in biomechanics and the theory of electrogenesis moves to a special (new) point of view. Now it is already firmly proved the absence of statistical stability of samples of parameters of tremorograms, teppingrams (and also many bioelectrical processes which provide regulation of movements, for example, electromyograms and electroencephalograms). There are no repeats not only of statistical distribution functions *f(x)* of samples $x_i(t)$ but also their spectral signal densities, autocorrelations, etc. for other 3TS-*complexity* parameters [14–16].

All this brings us to a conclusion about the end of further application of stochastic methods in the estimation of biomechanical parameters (and electro generating systems), which is so widely used now in biophysics, theory of electro generation, brain sciences. There is a need to create new invariants, new models and new theory to describe systems of the third type (according to W. Weaver's classification). From this point of view, we propose to introduce an analogue of the Heisenberg uncertainty principle in describing such unstable systems. In this case parameters of pseudo attractors are preserved and we can register static states of 3TS or their evolution (kinematics in phase state spaces).

In 3TS-*complexity* kinematics, we observe the motion of the center of the PA in the PSS or the change in the volume of the PA. Criteria are now being developed to estimate velocities and accelerations in 3TS kinematics (in PSS), which will avoid problems that are associated with the statistical instability of *x(t)* samples in the form of the Eskov-Zinchenko effect [14–15].

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