New information technologies in the estimation of the third type systems

V V Grigorenko1,4, M A Filatov1, N B Nazina1, L S Chempalova2 and S A Tretyakov3

1Surgut State University, Lenina pr., 1, Surgut, 628400, Russia
2Samara State Technical University, street Molodogvardeyskaya, 244, Samara, 443100, Russia
3Surgut State Pedagogical University, Surgut, st. 50 years of the Komsomol, 10/2, Surgut, 628417, Russia
4E-mail: grigv_84@mail.ru

Abstract. In the middle of the 20th century, W. Weaver, one of the founders of information theory, propose a hypothesis about special systems of the third type (living systems). In the article, W. Weaver directly points out the inability to describe living systems within the framework of determinism and stochastics. However, no one even tried to study the third type systems from these positions over the past 70 years. 20 years ago, we proved the Eskov-Zinchenko effect in the form of a lack of statistical stability of samples of human movement parameters. A new mathematical apparatus is now proposed to accurately describe the behavior of such systems. It is based on an analogue of Heisenberg's uncertainty principle.

1. Introduction

In 1948, the original article “Science and complexity” by W. Weaver was published, in which a general classification of all living and non-living systems was presented. However, over the past 70 years, no one paid attention to the fact that living systems (the third type systems - TTS) were brought outside the limits of all deterministic and stochastic science (DSS) by W. Weaver [1]. As a result, the basic problem of all science arose: how to describe such TTSs?

Almost 20 years ago, we proved the Eskov-Zinchenko effect (EZE), in which the statistical instability of samples in biomechanics was proved. Numerous repetitions of recording of samples of tremorograms (TMG) and teppingrams (TPG) have shown that obtaining match for two samples recorded consecutively (so that they match statistically) is an insoluble problem in biomechanics. As a result, a new method for estimating the parameters of TMG and TPG had to be developed, which was based on Heisenberg's uncertainty principle [2-5].

The main point in this development is the concept of uncertainty. At the same time, the uncertainty of the TTS has a completely different meaning than the currently existing uncertainty in physics and mathematics. This uncertainty is based on inequalities and it excludes any equations (which is generally accepted in deterministic and stochastic science - DSS) when describing TTS [2-5].
2. W. Weaver's hypothesis on the uncertainty of living systems

Let us note that the discussion of uncertainty in the description of living systems was raised by two Nobel laureates I.R. Prigogine [6], M. Gell-Mann [7], who declared “The End of Certainty” [6] and tried to find “Fundamental Sources of Unpredictability” [7]. However, both of these eminent scientists were deeply mistaken when they considered living systems (TTS) to be an object of quantum mechanics or Lorentz's theory of dynamic chaos.

Moreover, it was W. Weaver who first presented the classification of all systems of nature in the form of the first type systems (described in the framework of determinism), the second type systems (described in the framework of stochastics) and the TTS (W. Weaver did not provide a mathematical apparatus for their description). But W. Weaver clearly pointed out that the TTS-complexity is not an object of modern DSS. Let us recall his famous quote: “...as contrasted with the disorganized situation with which statistics can cope, show the essential feature of organization. In fact, one can refer to this group or problems as those of organized complexity.”

In this quote from [1], W. Weaver clearly separated the second type systems (stochastic) from the TTS, i.e. he believed that TTS cannot be described within the framework of deterministic models and in terms of stochastics. However, W. Weaver did not present any new theory. At the same time, the transition from determinism, where one point in the phase space of states (PSS) can be easily repeated many times, to stochastics, where a sample (a cloud of points in PSS) is needed to describe a the second type system, is obvious from the article. Following this logic, we have to operate not with one sample, but with a set of samples (samples of samples) in the transition from the 2 type systems to the TTS [8-13].

The question arises: what shall be done with the set of these samples? N.A. Bernstein [8], another genius of the 20th century, gave a hint to this question. In biomechanics, he hypothesized “repetition without repetition.” If we add these two hypotheses (on the TTS and on “repetition without repetition”), then it logically follows that we also have to check the possibility of the absence of repetitions (not just one point for the 2 type systems, but a whole sample for the TTS).

This was performed by us 20 years ago in biomechanics [8-15], and then in various other sciences about the human body [16-21]. Following the indicated logic of reasoning, we tested the possibility of statistical repetition of samples of the same parameter in the same subject [20-26].

3. Checking the statistical stability of samples in biomechanics

Following the logic of N.A. Bernstein's hypothesis (on “repetition without repetition”) in biomechanics and W. Weaver's hypothesis on the features of TTS (this is not an object of DSS), we began to register 15 samples of tremorograms (TMG) and tappingrams (TPG) consecutively in the same subject 20 years ago. The analog signal $x(t)$ from the sensor (this is the vertical movement of the finger, for TMG) was quantized with a frequency $\nu = 100$ Hz and a sample of 500 points was created (the period of TMG registration was 5 seconds). As a result, we obtained 15 TMG samples, which were compared in pairs using the Wilcoxon test $P$ and construct pairwise comparison matrices of TMG samples.

As an example, we present a typical pairwise comparison matrix of TMG samples, into which the probabilities $P_{ij}$ (for the $i$-th and $j$-th TMG samples) of statistical match of two compared samples are entered. If $P_{ij} \geq 0.05$, then we have (for this pair) the sampled population (high probability of their statistical match). Otherwise ($P_{ij} \leq 0.05$) this pair of TMGs does not statistically match. It is obvious that in table 1 the number $K$ of such pairs is critically small ($K=3$). This proves the loss of statistical stability, i.e. N.A. Bernstein's hypothesis and W. Weaver's hypothesis, since it is impossible to study the unique parameters $x(t)$ of the human body using statistical methods. The TMG samples (see table 1) are unique, the probability of obtaining the match of two neighboring ($j$-th and $j+1$ samples) samples ($P_{j,i+1}$) is extremely small (usually $P_{j,i+1} \leq 0.01$ for TMG and $P_{j,i+1} \leq 0.02$ for TPG).

In fact, such a result indicates that just as one point (in the PSS) cannot characterize the 2 type system (a sample is needed), so one sample cannot characterize the TTS-complexity. However, no one has yet proposed what can be used to study living systems (the TTSs). We propose to use samples of samples (15 pieces each, for example) and for them to construct pairwise comparison matrices $x(t)$ in the form...
of Table 1. In such tables, we find the numbers \( K \) (the number of pairs for which \( P_i \geq 0.05 \)) and from these numbers we can check the invariability of the TTSs (or about their changes). However, this requires numerous repeated recordings of samples, which is very inconvenient (a lot of time and calculations is needed).

Table 1. Pairwise Comparison Matrices of tremorogram’s samples for GDV subject (number of repetitions \( N = 15 \)). Wilcoxon test was used (significance level \( p < 0.05 \), number of matches \( k = 3 \)).

|    | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 | 13 | 14 | 15 |
|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|
| 1  | -  | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 2  | 0.00| -  | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.01| 0.00| 0.00|
| 3  | 0.00| 0.00| -  | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 4  | 0.00| 0.00| 0.00| -  | 0.01| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 5  | 0.00| 0.00| 0.00| 0.01| -  | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 6  | 0.00| 0.00| 0.00| 0.00| 0.00| -  | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 7  | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| -  | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 8  | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| -  | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 9  | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| -  | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|
| 10 | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| -  | 0.00| 0.00| 0.00| 0.00| 0.00|
| 11 | 0.69| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.30| 0.00| -  | 0.01| 0.00| 0.00| 0.00|
| 12 | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.02| 0.01| -  | 0.00| 0.00| 0.00|
| 13 | 0.00| 0.01| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| -  | 0.00| 0.00| 0.00|
| 14 | 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| -  | 0.00| 0.00|
| 15 | 0.00| 0.00| 0.12| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00| 0.00|

4. New invariants in the TTS models - complexity - are new information technologies

Due to the EZE, further application of stochastics in the estimation of the parameters of living systems is not practical. In this case, a fundamental uncertainty appears in the behavior of the TTS, which can be similar to the uncertainty of quantum objects. We should remind that Heisenberg’s uncertainty principle works in quantum mechanics, which has the form of inequality (1):

\[
\Delta x_1 \cdot \Delta x_2 = h/4\pi m
\]

In this inequality, \( x_1 \) is the coordinate of the particle, \( x_2 = dx/dt \) is the speed of its movement and \( m \) is the mass, we moved it to the right (at low speeds \( m = \text{const} \)). If \( h/4\pi m = Z_{\text{min}}, \) i.e. this is some constant, then this inequality, in fact, limits the magnitude of the variation of the phase coordinates \( x_1 \) and \( x_2 \). Following the analogy, we introduced some analog of this inequality for the TTS, but at the same time we wrote down 2 inequalities at once in the following form:

\[
\Delta x_1 \cdot \Delta x_2 \geq Z_{\text{min}} \leq Z_{\text{max}}
\]

We emphasize that the two constants \( Z_{\text{max}} \) and \( Z_{\text{min}} \) characterize \( E_{\text{max}} \) state of the given biosystem (there are two constants for a given subject). On the phase plane of the vector \( x(t) = (x_1, x_2)^T \), we can always construct a phase trajectory of movement \( x(t) \), which characterizes the sample of TMG or TPG for a given subject. As a result, we get a phase portrait for each sample (out of those 15 that are presented in Table 1, for example). Further, for any such phase portrait, we can represent (and calculate the area \( S \)) some rectangle, inside which the vector \( x(t) \) moves continuously and chaotically. Obviously, the area of this rectangle (let us call it a “pseudo-attractor” - a PA) characterizes the sample of TMG or TPG for a given subject.
Over the past 20 years, thousands of such PAs were considered and thousands of $S$ were calculated for these PAs, where $S=\Delta x_1 \cdot \Delta x_2$ ($\Delta x_i$ is the variation range along the coordinate of the finger $x_i$ and $\Delta x_j$ is the variation range along the $x_j$). Let us note that the value $S$ is equivalent to $Z_{max}$ in the system of inequalities (2). In other words, there is a special uncertainty in the values of $x_1$ and $x_2$, which has an analogy with quantum dynamics ($Z_{min}$ can always be obtained equal to 0, but this is true not for all TTSs).

Let us emphasize once again that the uncertainty on the parameters of the PA and on the phase trajectories of the state vector $x(t)$ for the TST in the PSS is introduced. This uncertainty has no analogues either in determinism (for the 1 type systems according to W. Weaver) or in stochastics (for the 2 type systems). The uncertainty of TTS is special, it is the basis of the construction of a new theory of chaos and self-organization (TCS) [9-14].

After examining 20,000 subjects and a detailed analysis of the results of more than one million samples, we found that the parameters of TMG, TPG in biomechanics, parameters of electromyograms (EMG) and electroencephalograms (EEG), RR intervals (RR) and other parameters of the heart (a total of 16 such parameters) cannot accurately demonstrate the statistical stability of the samples. In all cases, the EZE is registered when the second sample (when measuring consecutively) does not statistically match with the 1st sample. The probability (frequency) of such a statistical match $P_2$ is extremely small, it fluctuates for different biosystems in a small interval $P \in (0.01, 0.1)$. The highest $P_2$ appears for the EEG.

Now it becomes obvious that the EZE can be studied within the framework of calculating the number $K$ for samples (with $P \geq 0.05$) in pairwise comparison matrices or when calculating the areas $S$ for the PA. In this case, these areas $S$ can be invariants in estimating the physical and physiological state of a person. For example, we present a comparison of two samples of the PA areas for TMG of the same person with load (average PA area $<S_2>$) on a finger of 300 N and without load (average $S$ for the PA $<S_1>$) in table 2.

Table 2. The $S$ areas’ values for the PA of the GDV subject’s tremorograms samples (number of repetitions $N=15$) in a rest state and with a load of 3N (Pairwise Comparison of Wilcoxon criteria $p=0.00$).

|        | The S of PA $S1*10^{-8}$ for tremors without weight | The S of PA $S2*10^{-8}$ for tremors with weight (3N) |
|--------|---------------------------------------------------|---------------------------------------------------|
| 1      | 5.78                                              | 9.82                                              |
| 2      | 2.29                                              | 8.7                                               |
| 3      | 1.42                                              | 6.8                                               |
| 4      | 3.89                                              | 4.5                                               |
| 5      | 1.61                                              | 5.34                                              |
| 6      | 3.03                                              | 6.75                                              |
| 7      | 3.86                                              | 9.75                                              |
| 8      | 1.69                                              | 7.23                                              |
| 9      | 1.77                                              | 9.76                                              |
| 10     | 6.27                                              | 4.66                                              |
| 11     | 1.92                                              | 4.06                                              |
| 12     | 2.02                                              | 9.44                                              |
| 13     | 3.42                                              | 4.84                                              |
| 14     | 3.98                                              | 2.86                                              |
| 15     | 2.27                                              | 5.77                                              |
| $<S>$  | 3.02                                              | 6.81                                              |

Wilcoxon test, level of significance $p=0.00$
In table 2, it is shown that \( <S_i> > <S_2> \), this pattern is observed in all such studies. When the physiological state of the subject changes, there is always a change in the area \( S \) for the PA. However, these areas themselves are invariants (if the subject remains unchanged). This conclusion is obtained for thousands of calculated phase portraits of many areas. As a result, we come to a new technology in estimating the third type systems (living systems). We solved W. Weaver’s problem in describing (and comparing) the TTSs. \( K \) or the value of the area \( S \) for the PA of each subject shall be calculated [20-26].

5. Conclusions

More than 70 years ago, W. Weaver proposed a general classification of living and non-living systems. At the same time, he separated out the TTSs in a special way (all living systems). He emphasized that systems with self-organization (the TTSs) cannot be described in terms of stochastics (and even more so in terms of determinism). Following the logic of W. Weaver’s hypothesis, just as one point in the PSS cannot characterize the 2-type system, so a single sample of parameters \( x(t) \) of the TTS cannot characterize a stationary state of any living system [8-15].

Twenty years ago, we proved that any TMG sample was unique (statistically unrepeatable), which proves W. Weaver’s hypothesis on the TTS and N.A. Bernstein's hypothesis on “repetition without repetition.” For this proof, we repeatedly registered samples of TMG and TPG (15 samples in one series of experiments), and then construct pairwise comparison matrices of these samples. In each such matrix, the number \( K \) of pairs was found, for which the Wilcoxon test \( P \) was \( P \leq 0.05 \). This number \( K \) was proved to be very small (for TMG \( K \leq 0.05 \), for TPG \( K \leq 0.15 \)). As a result, W. Weaver’s hypothesis (on the TTSs) and N.A. Bernstein's hypothesis (on “repetition without repetition”) were proved.

A serious problem has arisen for the whole science, which is studying living systems or trying to implement the reduction of the TTSs (to describe living systems within the framework of physics and mathematics). For these purposes, we propose to calculate pairwise comparison matrices of samples (to find the \( K \) numbers) or to determine the parameters of pseudo-attractors (see table 2). In this case, the areas of the PA and the coordinates of their centers can be invariants for describing the TTS complexity. However, this refers to a different science (not DSS) and other models and methods. In fact, we offer new information technologies in the study of living systems.

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