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An Essay about the Functional Time of Environmental Interfaces Regarded as Complex Biophysical Systems

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Abstract: In the classical physics time is a continuous function eternally and evenly flowing as an absolute time dimension. However, the concept of “time’s cycle” is commonly applied as a metaphor in the biological sciences. First, we shortly elaborated the issue of time in physics and biology and then we considered the term of the *functional time* that is formed only as a result of consistent change of qualitatively new states of concrete, final material objects and processes. Further, we described a model for signaling in the process of energy exchange between environmental interfaces (EIs), specifically using three EIs that send signals during that process. Finally, we established the *functional time* barcode which is a representation of the system states through the chronological time.

Keywords: Biological time; functional time; environmental interface; biophysical modeling.

1 INTRODUCTION

1.1 Time in physics and biology

In the classical physics the time is a continuous function, generally valid, eternally and evenly flowing as an absolute time dimension. Traditionally, time has been modeled as a basic variable taking its values from an interval on a real axis. Although special relativity introduced Lorentz transformations mixing rectilinear time and space axes, while general relativity introduced curved space-times, the concept of a single underlying time dimension parameterized by a real interval remained. The pervasiveness of this concept was largely due to the success of the models it supported, in particular to the expression of physical laws by differential equations which ultimately relied on the limiting process, inherent in the notion of a (total or partial) derivative. Despite this success at the computational level, it has long been clear that the truly ramified nature of time cannot be captured by what amounts to a mathematical convention (Smith, 2003). In our everyday lives we have the sense that time flows inexorably from the past into the future; water flows down-hill; mountains erode; we are born, grow old, and die; we anticipate the future but remember the past. Yet almost all of the fundamental theories of physics, like classical mechanics, electrodynamics, quantum mechanics, general relativity, and so on, are symmetric with respect to time reversal. The only fundamental theory that picks out a preferred direction of time is the second law of thermodynamics, which asserts that the entropy of the Universe increases as time flows towards the future (Clausius, 1865). This provides an orientation, or arrow of time, and it is generally believed that all other time asymmetries, such as our

sense that future and past are different, are a direct consequence of this thermodynamic arrow (Eddington, 1928; Price, 1996; Feng and Crooks, 2008). In contrast with classical physics where time is a continuous function, generally valid, eternally and evenly flowing as an absolute time dimension, in the biology, time is in essence of cyclical nature (physiological peridioticies). The apparent antinomy concerning "time's-arrow" and "time's cycle" has already been discussed thoroughly in Gould [1987], particularly the meaning of time in the geological sciences. It should be recalled that the paradigm of "time's arrow" is prevalent in physics, as exemplified by Price [1996], while the concept of "time's cycle" is commonly applied as a metaphor in the biological sciences (Günther and Morgado, 2004). Biological time is a term that is often present in complex systems. A comprehensive sampling of some of the various space and time phenomena that have appeared in studies of biology and complex systems is given in Smith [2003]. Here, we will just count them: psychological spaces and times (*normal psychological time, pathological space time*), statistical system time, logarithmic time (*organic, thermodynamic, demography*), logistic equation and route to chaos and travel time.

In biology, the space-time organization of biological systems is one of their main features. Analysis of biological systems is a major problem of the modern theoretic and integrative biology, and analysis of space-time organization enables the most effective way to study the structure and function of biological systems merged together. However it is known that in spite of the shown concern to the space-time organization of biological systems, this problem has not received proper reflection in researches (Lolaev, 1998). "Time appears to be the most important concept that underlies the theory of living systems. Whether time is part of reality itself or whether it is just one of our ways of perceiving reality by an imposed construct is a question, readily addressable with the endo-exo description." (Nikolaeva-Hubenova, 2001). According to Kampis [1994], from the internal viewpoint, time is an inexorably primary percept. It cannot be cancelled or altered. For an inner observer, "time has neither velocity nor direction. Whatever direction or speed is assumed by the time variable, the same holds for the internal observer, and there is no difference or displacement to notice. Internal time sets its own tempo and rhythm, with no observable consequence." (Lolaev, 1996).

1.2 The functional time

Science up to nowadays operates by postulated concepts of time invented by men and inadequately reflecting objectively real, or according to Lolaev's terminology the *functional time* (Lolaev, 1996). According to him, the objectively real, *functional time* is formed only as a result of consistent change of qualitatively new states of concrete, final material objects and processes (each object is a process). Therefore, each material process forms its own time in which one it only exists. Thus, it becomes clear that the objectively real, *functional time* is not the universal form of substance being but the function of concrete final material things, phenomena and processes characterizing the duration of their existence. We call the objectively real time *functional* because the existence of time and all of its properties wholly depend on the quality changes happening in objects and processes forming them. Here, by "objective" we suppose quality of physical existence in space and time, and thus functioning independently of judgment of external observer. Therefore, complex biophysical systems (in further text, systems) have their own *functional time*. In this paper, we will consider the *functional time* of a complex system consisting of two biophysical subsystems, like environmental interfaces (EIs) that exchange energy among themselves. In Section 2 we will consider signaling in the process of energy exchange between EIs in a system, through (i) a short description of the model of energy exchange between EIs used to simulate the process whose functional time we intend to analyze (Subsection 2.1), and (ii) description of the signal strength in the EIs energy exchange (Subsection 2.2). Numerical simulation of forming the *functional*

time in the process of EIs energy exchange between EIs in a biophysical system is given in Section 3, where is elaborated (i) synchronization in the process of energy exchange in a three EIs system and its *functional time* barcode.

2 SIGNALING IN THE PROCESS OF ENERGY EXCHANGE BETWEEN ENVIRONMENTAL INTREFACES

2.1 Model of the energy exchange between environmental interfaces

Our contribution to understanding the *functional time* of EIs regarded as complex biophysical systems will be given trough considering a model describing two EIs, i.e. biophysical subsystems, which exchange energy among themselves. According to Mihailović et al. [2011b], this exchange (which includes also energy of physiological processes) can be described by a coupled system of logistics equations (*diffusive coupling*) having the form

$$\theta_{1,n+1} = (1-c)r\theta_{1,n}(1-\theta_{1,n}) + cr\theta_{2,n}(1-\theta_{2,n}) \quad (1a)$$

$$\theta_{2,n+1} = (1-c)r\theta_{2,n}(1-\theta_{2,n}) + cr\theta_{1,n}(1-\theta_{1,n}), \quad (1b)$$

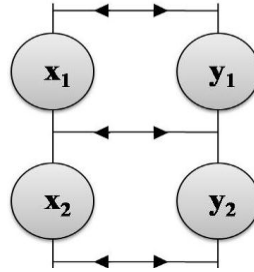


Figure 1 Schematic diagram of *diffusive* coupling given by Eqs. (1a)-(1b).

where θ ($0 \leq \theta \leq 1$) is the dimensionless temperature representing energy state of the EI. This model supposes existence of two EIs between which there is exchange of the energy (Figure 1). Such coupling tends to equalize the instantaneous states of the interfaces participating in the exchange (θ_1 and θ_2). The parameter r is the parameter for the logistic map and c (coupling parameter) is a measure of the energy exchange between the two interfaces, with $0 \leq c \leq 1$. Following the work by Mihailovic et al. [2011b], the parameter r can be different in Eqs. (1a-1b). Assuming that this exchange takes place between two interfaces, the exchange is periodically violated by changes of environmental conditions, i.e. through changing values of parameter r in the logistic equation. If the exchange takes place so that Lyapunov exponent (LEX) is less than zero then it is synchronized. However, if the environmental conditions are changed, then a jump comes to the positive values of the LEX during the “shock” (Mihailović and Balaž, 2012a). We can talk about the time of energy exchange when the system is synchronized in a more or less the same time intervals. So, in this system, in terms of astronomical time, observer can see the process of energy exchange between EIs as a measurable and visualized signal. Considered complex system generates its *functional time* by the process that is based on the principles behind the mechanism of energy exchange between EIs. This model comprises the following parameters: (1) c_i that represents coupling parameter of the i th EI and (2) parameter r that includes collective influence of environmental factors. For purpose of this paper we consider multi system in the form of interfaces ordered in a chain (cells, grid cells in atmospheric modeling, etc.). Each interface is coupled to its neighbor through coupling by mapping given in Mihailovic et al. [2011a] as it

was similarly done in Rajesh and Sinha [2008] and Ghosh et al. [2010]. According to Mihailović and Balaž (2012b), the system of coupled difference equations for N EIs exchanging the energy can be written in the form of matrix equation

$$\mathbf{A} = \mathbf{B} \cdot (\mathbf{C} + \mathbf{D}) \quad , \quad (2)$$

where

$$\mathbf{A} = \begin{bmatrix} x_{1,n+1} \\ x_{2,n+1} \\ \vdots \\ x_{k-1,n+1} \\ x_{k,n+1} \\ \vdots \\ x_{N-1,n+1} \\ x_{N,n+1} \end{bmatrix}, \mathbf{B} = \begin{bmatrix} 1 & 1 & 0 & 0 & \dots & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 & \dots & 0 & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & \dots & 1 & 1 & \dots & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 1 & \dots & 0 & 0 \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ 0 & 0 & 0 & 0 & \dots & 1 & 1 & 0 \\ 0 & 0 & 0 & 0 & \dots & 0 & 1 & 1 \end{bmatrix}, \mathbf{C} = \begin{bmatrix} (1-c_1)rx_{1,n}(1-x_{1,n}) \\ (1-c_2)rx_{2,n}(1-x_{2,n}) \\ \vdots \\ (1-c_{k-1})rx_{k-1,n}(1-x_{k-1,n}) \\ (1-c_k)rx_{k,n}(1-x_{k,n}) \\ \vdots \\ (1-c_{N-1})rx_{N-1,n}(1-x_{N-1,n}) \\ (1-c_N)rx_{N,n}(1-x_{N,n}) \end{bmatrix}, \mathbf{D} = \begin{bmatrix} c_1rx_{2,n}(1-x_{2,n}) \\ c_2rx_{3,n}(1-x_{3,n}) \\ \vdots \\ c_{k-1}rx_{k,n}(1-x_{k,n}) \\ c_krx_{k+1,n}(1-x_{k+1,n}) \\ \vdots \\ c_{N-1}rx_{N,n}(1-x_{N,n}) \\ c_Nrx_{1,n}(1-x_{1,n}) \end{bmatrix} \quad (3)$$

with condition $\sum c_i = c$ with $0 \leq c_i \leq 1$, while θ_i represents dimensionless temperature of EIs ordered in a chain. Solution of the system (3) gives us their values in time and space.

2.2 Signal strength

In order to demonstrate that each part of a complex system has its own intrinsic space-time (Smith, 2003), i.e. *functional time*, we consider a complex system consisting of three EIs that exchange the energy and send signals to an observer.

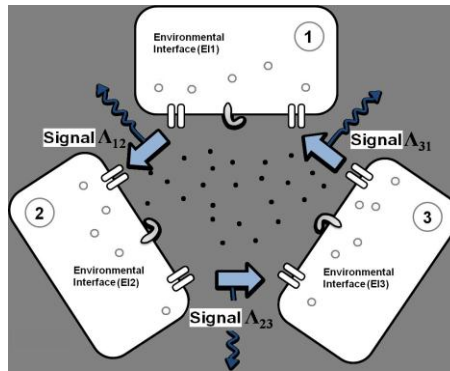


Figure 2 Schematic representation of a simple model of three interacting environmental interfaces with the corresponding signaling.

As it is seen in Figure 2, interfaces compose a complex biophysical system consisting of three components, i.e. (E1 vs. E2), (E2 vs. E3) and (E3 vs. E1). They exchange the energy sending single signals Λ_{12} , Λ_{23} and Λ_{31} . Signal reaching the observer indicates that system remains functional until any signal reaches its location. In the model this condition is satisfied when there is synchronization in energy exchange between any two or three EIs sending single, double or triple signals. On this place let it be noted that in biological systems and biophysical as well, there are components that when they lose their functionality then the system is terminated. Those components we will call - *cardinal components* of the system. If the biological system does not send any signal to the agent that does not come from the *cardinal component (non-cardinal)* it means that

system is (i) in function sending other signals but without signal from that component or (ii) that component waits to be synchronized with other ones in order to send the signal. In general case when a biophysical system has N EIs, then the number of signals sent to agent is $i = n(n-1)+1$ emitted by $j = C_2^N$ components. We suppose that the strength of the single signal, emitted from this biophysical system towards the observer, is given in the functional form $\Lambda = \Lambda(\lambda)$, where λ is LEX, that is calculated for the energy exchange between each two EIs in the biophysical system. For any $\lambda \geq 0$ the energy exchange between EIs is considered to be unsynchronized and corresponding signal strength from that component is equal zero (Mihailović and Balaž, 2012a).

3 NUMERICAL SIMULATION OF FORMING THE FUNCTIONAL TIME IN THE PROCESS OF ENERGY EXCHANGE IN THE BIOPHYSICAL SYSTEM OF THREE ENVIRONMENTAL INTERFACES

We will show an example of forming the functional time in the process of the energy exchange in the biophysical system of three EIs using the model described in Section 2. Synchronization is well-known collective phenomenon in various multi-component physical and biological systems (Pikovsky et al., 2003). The exchange of information (coupling) among the components can be global (all-to-all) or local (nearest neighbors). Depending on the various intrinsic and extrinsic factors, the coupled dynamics can exhibit different types of synchronization such as complete synchronization, phase and lag synchronization, intermittent phase synchronization, etc. where, depending on the signal type we consider, synchronization is either local or global (indicated by the negative values of the corresponding Lyapunov exponent). Extending the approach, for three coupled maps representing energy exchange between EIs, we study the stability of the fixed point by linearizing the three EIs system (3)

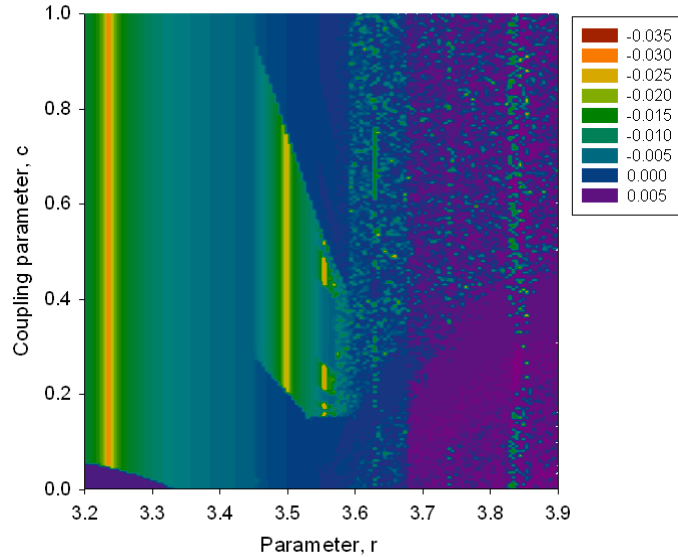


Figure 3 Values of LAX (Lyapunov exponent, $\lambda < 0$) in the process of energy exchange in the three EIs system over values of coupling parameters $c_1 = c_2 = c_3 = c/3$ $c \in [0,1]$ and parameter $r \in [3.2,3.9]$.

$$\mathbf{Z}_{n+1} = \zeta_n \mathbf{Z}_n \quad (4)$$

where ζ_n is the Jacobian of the three component system evaluated in (x_n, y_n) and $Z_n = (x_n, y_n)$. By iterating Eq. (4) one obtains

$$Z_{n+1} = \left(\prod_{s=0}^n \zeta_s \right) Z_0 \quad (4)$$

and thus we get LAX

$$\lambda = \lim_{n \rightarrow \infty} (\ln \| \prod_{s=0}^n \gamma_s \| / n). \quad (5)$$

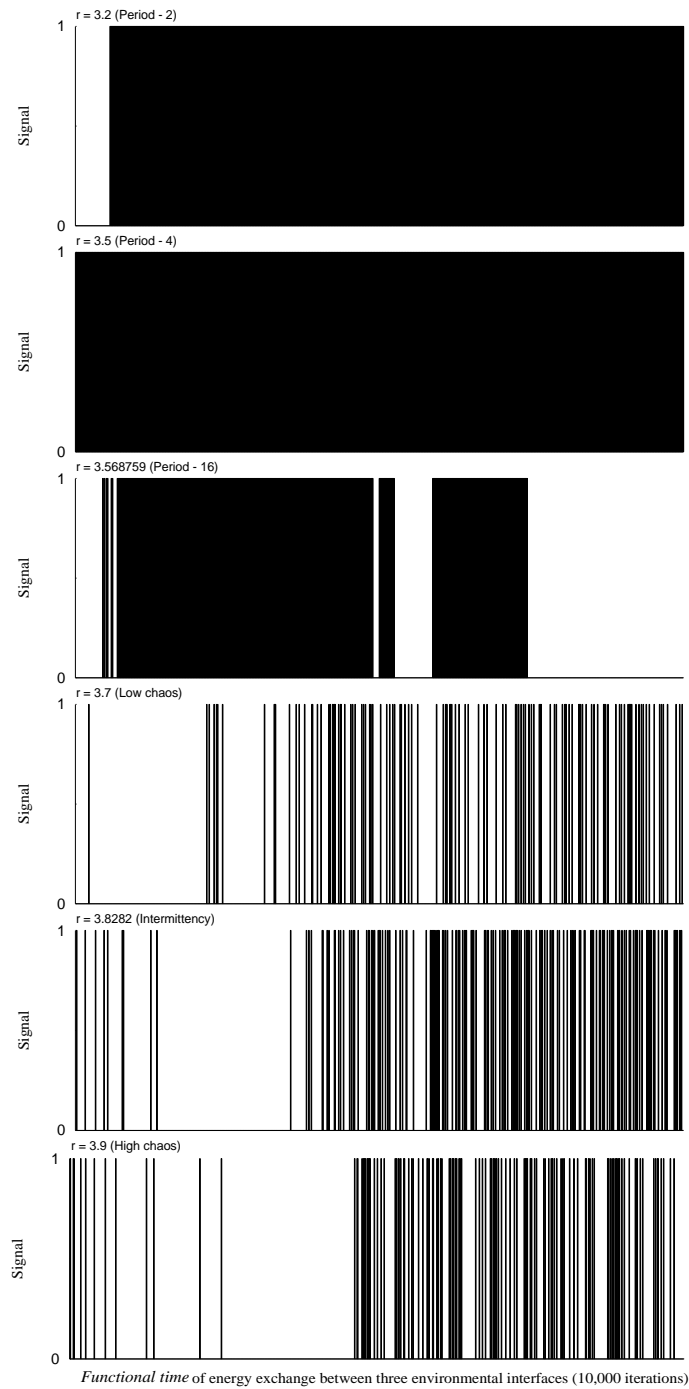


Figure 4 The *Functional time* of energy exchange in three EIs system for different values of the parameter r .

We analyze the all-to-all EIs synchronization in energy exchange between three EIs in (c, r) space. A synchronization signal with zero strength (0) or (1) corresponds to $\lambda \geq 0$ and $\lambda < 0$, respectively. We used the following values of coupling parameters c_1, c_2, c_3 ($c_1 = c_2 = c_3 = c/3$ $c \in [0, 1]$) and parameter $r \in [3.2, 3.9]$. In Figure 3 are shown values of LAX in the process of energy exchange in three EIs system. From this figure is seen that the synchronization is achieved for $r \in [3.2, 3.66]$ and for all values of coupling parameter c except for their values in the lower left corner. Further, we consider synchronization through exchange of signals. Having in mind binary coding, representing either non-synchronized state or synchronized one, we can establish a barcode of the *functional time* in the process of energy exchange in three-EIs-system. We call this code the *functional time* barcode which is a representation of the system states through chronological time (Rosen, 1991), which shows data about the process of biochemical substance exchange. It represents states by varying width of parallel lines and spaces between them, indicating whether system is synchronized or not, and may be referred to as linear.

As mentioned above we deal with the system of three EIs that exchange the energy described by the mapping given by Eq. (3). So we have three EIs in the system and one process (process of exchange), sending $3(3-1)+1=7$ signals. The signal strengths are calculated for each two interacting EIs (Mihailović and Balaž, 2012b). Since the *functional time* is related to the state of the system, in this experiment we defined the state in the following way: the one state is the period in which the system is passing through one thousand iterations with monotonic increase of entropy. Transition from one state to another one is defined by a jump of the entropy to the next state. Figure 4 shows the *functional time* barcode for energy exchange for the three-EIs-system for all values of the coupling parameter c and six values of the parameter r , after 10,000 iterations. Let us note that after each iteration we checked whether cross sample entropy of each component is below the threshold, using procedure defined in Mihailovic and Balaž [2012a]. If that condition was satisfied then the corresponding value, either 0 (synchronized) or 1 (non-synchronized), is associated to the state. This barcode shows a "history" of the *functional time* of the considered process as a part of functioning of the three-EIs-system.

4 CONCLUSIONS

In this paper we considered the concept of the *functional time* in the process of energy exchange between EIs. First, we shortly elaborated the issue of time in physics and biology and then we considered the term of the *functional time*. It is formed only as a result of consistent change of qualitatively new states of concrete, final material objects and processes. Further, we described a model for signaling in the process of energy exchange between EIs. In numerical simulation about forming the *functional time*, of this process, specifically we used three EIs that send signals during the process of energy exchange between them. Finally, we established the *functional time* barcode which is a representation of system states through chronological time, which shows data about the process of energy exchange to which it attaches. It represents states by varying width of parallel lines and spaces between them, indicating whether system is synchronized or not.

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