Self-organization of holistic systems as a result of spontaneous tending to equilibrium

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Methodological aspects of the problem of spontaneous self-organization of systems having various origins are considered: uncertainty and ordering in their evolution, expediency of the evolution, and regular tending of the systems to equilibrium. The general equation of regularity is suggested. The regularity can manifest itself in formation of different systems like planets, soils, river floodplains, sea and lake shores, as well as biological, social-economic, and technical ones. Self-regulation peculiarities of systems of various origins are analyzed.

I cannot believe that God would choose to play dice with the universe.
Albert Einstein

Introduction

Global changes in the environment and climate on the Earth, as well as the growing anthropogenic impact on these changes were comprehensively discussed and evaluated in Agenda 21, the Rio Declaration on Environment and Development adopted at the United Nations Conference on Environment and Development (Rio de Janeiro, 3–14 June 1992).[1] Active participation of Academician V.A. Koptyug (at that time the Chairman of the Siberian Branch of the Russian Academy of Sciences) in this Conference promoted the extension of researches in this field in the framework of SB RAS programs and has led, in particular, to formation of the Laboratory of Sustainable Development Problems (now the Laboratory of Self-organization of Geosystems) in the Institute of Optical Monitoring in 1994.

The main research field of the Laboratory headed by the author of this review was formulated from the outset as the study of general regularities in development of nature and society, as well as strategy of their interaction in the interests of sustainable development. The research into this problem is supported by the Russian Foundation for Basic Research [Grants No. 94–05–16328 "Synergetic of geomorphosystems" (1994–1996), No. 01–05–65152 "Self-organization of fluvioglacial catastrophes" (2001–2003)], Russian Humanities Foundation [Grant No. 97–02–02212 "Synergetic and sustainable development of ecological-economic systems" (1997–1998)], and Soros Foundation [Grant CAE 011 (2000)]. In 2001 the Laboratory won grants of the Federal Program "Integratsiya" [No. E 0242] and the Russian Foundation for Basic Research [No. 01–05–79087] for organization of research missions.

A significant role in the research is played by the Russian Scientific Seminar on Self-organization of Stable Integrities in Nature and Society. Annual conferences of this Seminar include discussions of general methodic approaches to the study of regularities in evolution of systems of various origins with wide participation of Russian and foreign scientists and publication of the conference proceedings.[2–6] The Seminar is continuously supported by the Russian Foundation for Basic Research (grants for organization of seminars for 1998–2001).

The scientific direction of the Laboratory corresponds closely to one of the subjects of the Research Program of the Department of Oceanology, Atmospheric Physics, and Geography of RAS, namely, "Geographic foundations of sustainable development of nature and society." The direction falls within the main research problems of the IOM SB RAS, and the results obtained by the Laboratory can be interesting and useful for specialists dealing with the study of regional and local natural and climatic changes.

Uncertainty and order in evolution of systems

In the last decades, the idea of evolution of dissipative, far from equilibrium structures, developed by the well-known physicist Ilya Prigogine, is gaining acceptance in the world outlook understanding of the fundamental laws of thermodynamics. The essence of conclusions, following from works of Prigogine[7,8] and his numerous followers, is based on the law of degradation of energy. The law postulates that the system dynamics (especially, human technological activity) includes asymmetry – *unidirectionality, irreversibility* of energy distribution: the diffusing energy does not concentrate spontaneously and does not return to the initial state; to do this, some work should be done and, consequently, some energy should be expended. It is assumed that the law of degradation of energy directly relates the increase of entropy and the *"positive direction of time,"* that is, time is irreversible,

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since the process accompanied by irreversible growth of entropy is irreversible. Based on this statement, Prigogine believes that the future is characterized by the higher entropy,[7] that is, degradation and de-organization increase in all systems. This is a basis for categorical statements that become increasingly popular now, such as *the equilibrium cannot be the aim of the world, as it excludes evolution* or *the aspiration for maximal disorder limited by some conditions is the main law of nature*.[9] However, three important circumstances are ignored here.

First, the law of degradation of energy characterizes only the second, final part of the cycle of the system evolution, namely, the degradation; it does not apply to the first stage of the system evolution, to the period when systems have been forming, and their sizes, complexity, variety, and other characteristics of the internal content and form increased and qualitatively improved. This process could apparently continue up to some equilibrium, steady state, until the expense Q of matter, energy, and information from the environment stopped and significantly decelerated. It is natural to believe that in the period of system self-organization this process was accompanied by the decrease of entropy (S): $dS \to 0$. For example, formation of such megasystems as stars and planets (Sun, Earth, etc.) at the initial stage was accompanied by the increasing production and release of thermal energy. And, as it must be according to the main laws of physics, the work done increased $dA(t) \to A_{max}$, and $dS(t) \to \min$, what follows directly from the fact of formation of high-ordered spherically symmetric planetary structures with regular distribution of layers, density, etc. It is natural that this process was accompanied by energy dissipation with the increasing rate.

Second, the above approach ignores the fact that formation and evolution of holistic self-organizing structures are possible in the only case – when the fluxes of matter, energy, and information from the environment (being a combination of numerous systems) or from some other systems are ordered. Matter, energy, and information fluxes acting in a random way can form only chaos – complete uncertainty of evolution. We can state that all known laws of evolution of the matter are such, because they reflect stable deterministic relationships showing themselves similarly under similar conditions. They characterize the order, a sort of a deterministic attractor, to which some or other process tends regularly.

Third, the conclusions on dissipation of the energy and irreversibility of evolution are drawn based on consideration of one system, often technical, artificial, and in isolation from its creator – a human, what is inadmissible at the rigorous approach to the principles of separation of self-organizing systems. All technical systems, including cybernetic ones, are parts of self-organizing social-economic systems, which organize both the order of functioning of technical systems and the order of technical fluxes. It should be emphasized that any ordered organized integrity dissipates the ordered flux of matter M, energy E, and information I (MEI) into the space. This is also true for technogenic systems when they are considered in relation to the human. The ordered, organized fluxes, in their turn, objectively assume formation of other systems based on them. Taking into account these circumstances, we can resume that the fluxes of matter, energy, and information, stringing systems of different ranks, finally form a closed chain being nothing else than a system of a higher hierarchic level in organization, genetic diversity, work, etc.

Consider, as an example, an holistic system – the Earth, with a complex diversity of various systems of different rank, from abiotic and biological to social and technical, evolving on it. The Earth and all systems existing on it were formed at the initial stage exclusively at the expense of accumulation of matter, energy, and information coded in the strict sequence of events and stratification of matter. The process of energy dissipation (flux q into the environment) in this period of system self-organization could not be decisive, since $dQ(t) - dq(t) > 0$. In other words, at the initial stage of system formation, the colossal and vast, in its consequences, work was done on the extremely large scale and this work was directed against scatter of matter, at its accumulation and concentration, regularly accompanied by production of energy in amounts exceeding its dissipation.

What forces performed this work?

At $M > M_{cr}$ ($M_{cr} = 10^{21}$ g is the mass of matter, whose gravitational energy is sufficient for spontaneous gravitational accumulation), these are mostly the forces of weak interactions. At very large, postcritical masses ($M = 0.03–60$ of the solar mass), these are the forces of weak and strong interactions leading to formation of spherically symmetric structures and accompanying by the growth of pressure and temperature up to the values sufficient for development of thermonuclear reactions. At this stage, the process proceeded irreversibly in the "*positive direction of time*" according to Prigogine, but not in accordance with the law of energy degradation: the structural order of systems and amount of thermal energy increased, as well as the work done, and the process was accompanied by the decrease of entropy.

It is natural that the matter and energy simultaneously and inevitably dissipated, but this dissipation proceeded against the background of prevalent accumulation.

It is correctly reasoned that the Earth, as a spontaneously self-organizing structure, falls in the category of closed systems. At least at the current stage of its evolution, it receives more energy and matter than releases into the environment, and mostly exchanges energy with the environment. The amount of matter coming to the Earth within the characteristic evolution time is negligibly small. The main sources of matter for terrestrial systems (abiotic systems, ecosystems, civilization systems) are the Earth's crust, atmosphere, and hydrosphere. The main sources of energy determining the evolution of terrestrial systems are solar thermal and radiant energy and the endogenous energy of the Earth. Judging from the rate of change of the Sun (for 5 billions years its mass decreased only by 0.01%), the amount of solar thermal energy coming to the Earth does not change significantly for the whole its history. The Sun radiance is almost unchanged as well.

Consequently, we can assume that formation and evolution of the Earth's geoshells determining the formation and existence of ecosystems proceeded due to the constant external source of energy. It is undoubted that this state will keep unchanged for the next billion years.

So, let us emphasize once again that the highly ordered flux of thermal and radiant energy comes to the Earth from the Sun; the endogenous flux of the energy of the Earth itself, at the expense of which the orogeny work is done, is ordered as well. The order is also present in the process of spatial variability of humidification of the atmosphere and formation of cyclones, which in combination with the relief of the Earth surface serve the main condition for accumulation of precipitation into water flows and formation of the highly organized water-bearing system. Just this system is one of inexhaustible and most pure sources of kinetic energy.

In Prigogine's view, we treat ourselves as a highly evolved kind of dissipative structure, and justify, in an objective way, the distinction between the future and the past.[7] However, he ignores that we should simultaneously consider ourselves, as well as any other integral structure, as an associative structure-ensemble, in which the integration and concentration of *MEI* prevail over dissipation at the initial stages of its formation and evolution. Just this causes formation of holistic structures, which process *MEI,* coming from the environment in the ordered (consequently, negentropic) flux, into two qualitatively different forms:

(1) new ordered and, consequently, also negentropic flux q released into the environment, quantitatively equal $q = Q - M,$ where Q is the expense of *MEI* in the flux coming to the system and M is the expense of matter, energy, and information for organization and evolution of the system itself;

2) the second form is the material system itself, which occupies a certain volume with its own individual features reflecting in the state and dynamics of the environment (system of a higher rank), i.e., it becomes a part of the environment structure.

Thus, the ordered *MEI* flux from the Sun to the Earth does not scatter, in essence, but concentrates in an infinite set of various systems, starting from land and water and ending with microorganisms and bacteria. This flux is almost completely absorbed by the variety of systems functioning at the expense of each other and for each other. Thus, all holistic structurally ordered self-organizing formations should be called *dissipative-integration* systems.

Prigogine relates the second law of thermodynamics to the "positive" direction of time toward the increasing entropy.[7,8] However, *the arrow of time* is determined not by irreversibility and the law of increasing entropy, but by formation of something *new*, different from *old*. *The arrow of time* is nothing else than *irreversible negation of the old by the irreversibly formed new.*

Just thanks to this, in my opinion, there exists the order in the universe, and the chaos arises due to replacement of the obsolete order, not corresponding to the present conditions of the environment, with the new one. Thus, chaos characterizes the transition of a system from one state into another, qualitatively different.

Based on the above-said, we can state that formation and evolution of all material (and even abstract) self-organizing integrities, including planetary systems, involve two simultaneous processes: integration and accumulation of matter, energy, and information and formation of the *MEI* dissipation flux (formation of chaos). Any holistic system, including abstract ideas, possesses the immanently inherent property of expediency, which consists in spontaneous and appropriate tendency to equilibrium: dynamically movable thermodynamic equilibrium in the form of so-called equilibrium or static regime.

The spontaneous tendency toward equilibrium is formulated as follows: *dynamics of dimensions* $(M(t))$ *of holistic systems is proportional to the difference in matter, energy, and information expenses in the flux* $Q(t)$ *coming from the environment (F-flux) and the flux* $q(t)$ *released into the environment (D-flux).* In the differential form, this regularity can be written as follows:

$$dM/dt = Q(M, t) - q(M, t). \qquad (1)$$

Manifestation of the tendency toward equilibrium in dynamics of abiotic systems

Formation of planets

In my earlier publications,[10,11] I first have put forward the statement that the conditions for formation of planets were formed only in the plane of ecliptic, where the gas–dust cloud under the effect of gravitation due to the Sun has been structured into spiral branches. All particles from edge parts of the cloud moved toward the center of gravity along spiral trajectories. Since the mass $m(t)$ of the formed planets (planetesimals) and acceleration $g(t)$ increased in the process of movement, the radius $R(t)$ of the spiral decreased to some value R = const corresponding to the condition

$$GMm/R^2 - mv^2/R = 0. \qquad (2)$$

Here the first term is the force of gravity and the second one is the centrifugal force. Naturally, $g(t)$, $m(t)$, and $R(t) \to$ const before achievement of this condition. The equation of transition of spiral planetary trajectories into circular ones is the following:

$$dR/dt = F(R, t) - F_c(g, m), \qquad (3)$$

where $F(R)$ is the force of gravity due to the Sun; $F_c(g, m)$ is the centrifugal force of a new planet. Apparently, the limited cycle of planets, that is, transition to the circular orbit, was possible if the distance from the planet origin to the Sun was sufficiently large. Otherwise, bodies fell on the Sun.

Satellites of planets, centers of accretion of the third order, were formed in the similar way.

Formation of soil due to rock weathering and denudation

Let H be the thickness of the soil layer, Q be the amount of fragmental debris due to weathering that forms the layer $\Delta H(t)$ (in essence, it is the rock expense due to which their height decreases), and q be the expense of matter (denudation) in the new layer ΔH. Then, taking into account that Q and q are the functions of the height H and time t, the dynamics of the layer thickness is described by the following equation:

$$\mathrm{d}H/\mathrm{d}t = Q(H, t) - q(H, t). \qquad (4)$$

It is known that $Q(H, t)$ decays by the logistic law: it decreases proportionally to the difference of some limited value $H_{\lim}$ and the current value $\Delta h(t, H)$. Thus, $\mathrm{d}Q/\mathrm{d}t = H_{\lim} - h(t)$, i.e., it decreases tending to zero, and $q(H, t)$ increases with the increasing H: $q = pH^3 \sin a / 3\lambda$ (here p is the density of the friable matter, λ is the viscosity, a is the slope of the surface). Since the growth of the soil layer $\Delta h(t, H) \to 0$ and $\Delta q(t, H) \to \max$, there comes a moment when $Q(H, t) - q(H, t) \to 0$ and $\mathrm{d}H/\mathrm{d}t \to 0$ at continual processes of weathering and denudation. The model of the process was described in Refs. 12–14.

Floodplain dynamics

River floodplain is a periodically flooded surface and its dynamics is inseparably linked with the dynamics of the riverbed. It is formed only in the case of simultaneous horizontal and vertical displacement of the riverbed, i.e., at $H = f(x, y)$ (here x and y are the horizontal and vertical coordinates). If $\mathrm{d}y/\mathrm{d}t = 0$ (river bottom does not lower), then the river, shifting in the horizontal plane, leaves behind a low surface, whose flooding (the total duration of flooding) varies from the maximal value at the initial time t_0 to zero at t_n. The total amount of matter accumulated on the floodplain surface varies similarly by the obvious reasons. Thus, the floodplain height $H(t)$ increases proportionally to the difference between the amount $Q(t)$ of sediment accumulated for the period of flooding (warp thickness per unit area) and the amount $q(t)$ of the matter removed for the time between floods. And in this case, $\Delta Q(t) \to 0$ and $\Delta q(t) \to \max$ as the floodplain height $H(t)$ approaches the limited height $H_{\lim}$ equal to the maximal height of floods. Herefrom we can easily find the dynamics of matter expenses in the both fluxes, and the equation of variation of the floodplain height with time has the following form[15,16]:

$$\mathrm{d}H/\mathrm{d}t = Q(H, t) - q(H, t). \qquad (5)$$

Without radical changes, this model can account for the river cutting-in, accumulation of material onto the floodplain from slopes, denudation from the floodplain surface, as well as dynamics of movable floodplain islands and plant communities on them.[17] For example, their age is determined by Eq. (5) and the period T of island motion.

Formation of erosion-denudation relief

The dynamics of relief forms is determined by directed changes of their volume V and surface area S at the known physical properties of the matter determining morphological indices. Because the rate of the growth of relief forms is determined by matter expenses P and Q in respectively F- and D-lithofluxes (F is the deep lithoflux and D is the exogenous lithoflux), the dynamics of geomorphosystems is described by the equation[18,19]:

$$\mathrm{d}V/\mathrm{d}t = P(S, t) - Q(S, t). \qquad (6)$$

If the volume V of the matter contained in relief forms is taken as a size of some ecosystem, then we have the following system of equations[20,21]:

$$\begin{cases} \dfrac{\mathrm{d}V(t)}{\mathrm{d}t} = P - Q(t), \\ \dfrac{\mathrm{d}Q(t)}{\mathrm{d}t} = kS^m[V(t)], \end{cases} \qquad (7)$$

where k is the denudation coefficient; m is the fractional index of fractal growth of the relief surface area.

This system is nonlinear because of the nonlinear change of the surface area S as a function of the volume of forms.

Formation of sea and lake shores

Evolution of sea shores, lakes, and artificial water storages is an illustrative example of the considered regularity. Sea trangressions (or creation of artificial storages) intensify abrasion of shores and accumulation of fragmental material in lagoons and bays. This is accompanied by formation of a series of storm waves, the distance between which regularly decreases to zero (Fig. 1). In this example, a lagoon has been filled for about 5000 years in accordance with the equation:

$$\mathrm{d}S/\mathrm{d}t = Q(S, t) - q(S, t), \qquad (8)$$

where S is the surface area of a shoreline shoal of a lagoon with unit width.

In Eq. (8) $Q(S, t)$ characterizes the change in the position of the shoreline due to accumulation of fragmental material in lagoon (the shore invades the sea). However, it is subjected, at the same time, to increasingly intense abrasion accompanied by alongshore transport of material $q(S, t) \to \max$. Therefore, smaller amounts of material are accumulated in the lagoon with time, the distance between the accumulative waves decreases, and the system goes to the established dynamically equilibrium mode of evolution, i.e., objectively $dS/dt \to 0$, but this state is never achieved.

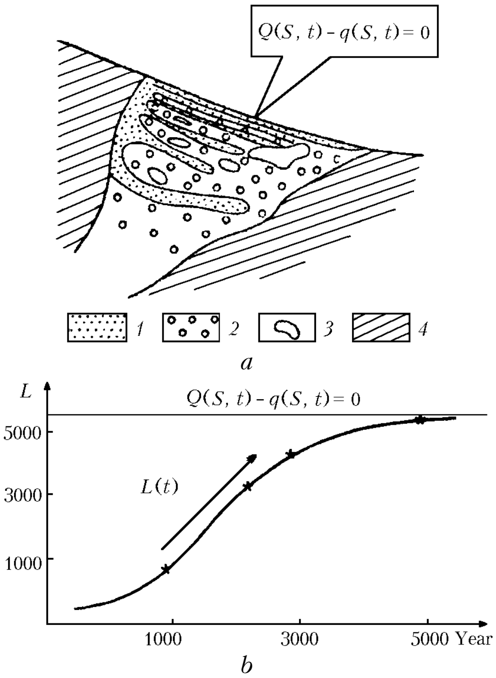

Fig. 1. Formation of dynamically equilibrium shore in Mukhtel Bay (Sea of Okhotsk): arrangement of storm waves (*a*): storm accumulative waves *1*, accumulative plain *2*, lakes *3*, and mountains *4*; the distance L between waves as a function of time (*b*).

This regularity allows abrasion of shores of artificial storages to be predicted sufficiently accurate. This methodology was put in the basis for prediction of abrasion processing of shores in Zeiskoe and Bureiskoe artificial water storages.[22,23]

Formation of accumulative plains at the filling of tectonic basins

As is seen from Fig. 2, the filling of tectonic basins damps with time and the amount M of the fragmental material approaches a constant determined by the amount of material coming into the basin and leaving it.

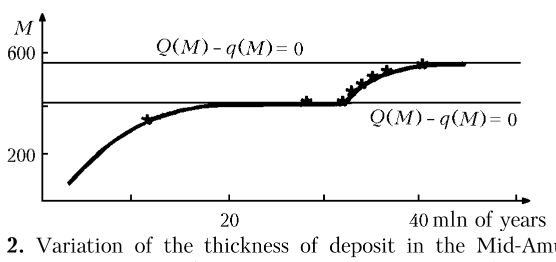

Fig. 2. Variation of the thickness of deposit in the Mid-Amur Basin. The rate of deposit accumulation slows down as $dM/dt = Q(M, t) - q(M, t)$. The break point characterizes the change in the conditions of deposit accumulation due to tectonic depression of the basin.

It follows from the plots that the state close to the dynamic equilibrium in Oligocene was broken due to the change of tectonic and climatic conditions. However, after these changes, the filling process was regular and directed at establishment of dynamic equilibrium under new conditions. The process of basin filling, as well as many other geological and geomorphological processes – formation of stratovolcanoes, mountains, plains, and others, is described by the equations similar to the above ones.

Manifestation of the tendency toward equilibrium in dynamics of biological systems and civilization

Dynamics of biological systems

The Lotka–Volterra models proposed in the 1930s (Ref. 24), as well as Poletaev models (Ref. 25) were likely among the first models, which used the equation of dynamics of complex self-regulating systems with nonlinear feedbacks for analysis of population dynamics. They were the models of competition between populations under the conditions of limited food resources, well-known as predator–prey models:

$$dN_1/dt = k_1N_1 - k_1\, N_1N_2,$$
$$dN_2/dt = k_2N_2 - k_2\, N_1N_2, \qquad (9)$$

where N_1 is the population of prey for the population of predators N_2; k_1 and k_2 are the coefficients characterizing the rate of increase of the populations N_1 and N_2, respectively.

The system of equations (9) describes the dynamics of predator and prey populations in their interactions. This model accounts for various relationships between different biosystems, for example, intraspecific competition in both the prey and predator populations. It allows consideration of more complex models of biocenosis dynamics with allowance for expenses of not only nutrients, but also energy.

Models of evolution of civilization

The interest in the models of global evolution of civilization has quickened in the last three decades. Active discussion was raised by the models developed by the group headed by Jay W. Forrester at the Massachusetts Technological Institute[26] and then by many other research teams. The most widely known are the works of the Club of Rome.

The Forrester system-dynamic approach to description of a global social-economic system is based on its representation in the form of a set of communicating vessels with various liquids imitating matter, energy, and information flowing through them. The amount of matter M in some vessel (an analog of a particular social-economic system) at every instant of time t is determined by the difference of expenses of materials: P_i coming from the environment and other vessels (sociosystems) and q_i released into the environment and other vessels (sociosystems).[26,27]

Thus, the general equation for dynamics of different indices of the civilization evolution has the form

$$\mathrm{d}M/\mathrm{d}t = P_i - q_i, \quad (10)$$

where $i = 1, 2, \ldots, n$.

For example, the equation for the capital K (as well as agricultural products, pollution, etc.) has the following form:

$$\mathrm{d}K/\mathrm{d}t = K_2 - K_1, \quad (11)$$

where K_2 is the increase of capital assets (capital, any other products) proportional to the population, and K_1 is the capital decrease due to wear and ageing. The demographic process is described by a similar equation.

Models of functioning of artificial (technical) systems

We can say literally that the progress of civilization (technical inventions up to modern cybernetic systems, nuclear power stations, artificial satellites, etc.) is determined by the limits of the objective regularity described above. A man, being a product of nature, in his intellectual and practical activity also obeys the genetically acquired general regularity of evolution, and he puts it, often unconsciously, in the basis of functioning of his inventions, artificial technical systems.

The generalized energy form of the equation of dynamics of various regulated technical systems is the following[28,29]:

$$B\mathrm{d}y/\mathrm{d}t = E_1 - E_2, \quad (12)$$

where $B\mathrm{d}y/\mathrm{d}t$ is the energy accumulated in the system; B is the constant of a system; y is a regulated parameter; E_1 and E_2 are the input and output energies.

Similar equations describe the dynamics of technical systems with torque:

$$J\mathrm{d}w/\mathrm{d}t = M_d - M_c ,$$

a receiver of a certain volume with communications for gas supply and removal:

$$\mathrm{d}G/\mathrm{d}t = Q_n - Q_p ,$$

technical systems with regulation of liquid level in reservoirs:

$$Fg\mathrm{d}H/\mathrm{d}t = Q_n - Q_p ,$$

and others.

Technical systems themselves do not fall in the category of self-organizing systems. Nevertheless, since they are a part of unique symbiosis of the intellectual anthropogenic and technical systems, they should be considered as a complex anthropogenic-technical self-organizing system, which possesses all features of self-organization: the spontaneous, genetically inherent in a man, striving for increase of order and decrease of entropy in the organized technogenic social-economic system.

Peculiarities of regulation of systems of various origins

The above equations describing the system dynamics are the equations of self-organization of holistic systems: the terms in the right-hand side are in a functional dependence on the regulated characteristics themselves. Since the second term always tends to the first term, then this functional dependence as a negative feedback, inhibits the process, namely, slows down the growth of matter, energy, and information in the system, reduces the mass to some dynamically equilibrium value slightly varying with time. The system goes into the category of self-organizing systems, the only system among all, which is capable to increase its order at the expense of matter, energy, information, and order (negentropy) from the environment. Taking into account these circumstances, we classify geosystems (abiotic systems) as self-organizing. A prominent example of such systems is the relief forms shown in Fig. 3 (Ref. 30) or shoreline shoals formed due to abrasion of shores. In this case, the chaotic, fully unordered process of formation of shores (or a waterlogged plain, Fig. 3) at the final stages changes into the process with surprisingly high structural order.

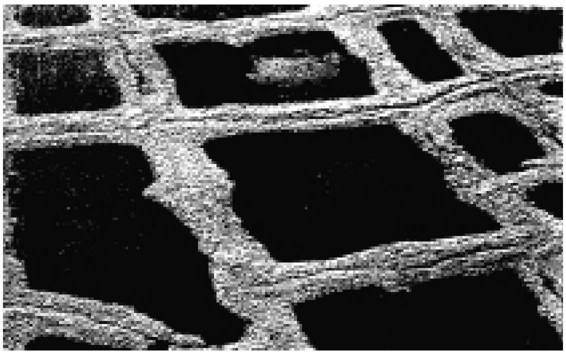

Fig. 3. Structural self-organization of cells similar to Benar cells in watered soil due to highly ordered diurnal variations of temperature with transition through 0° (photo of A.L. Washburn[30]).

It would be mistaken to believe based on the identity of the equations describing dynamics of different systems that the mechanisms of their self-regulation and self-organization have no principal distinctions. Natural systems have no specialized regulating units capable to determine the difference between the given and current states of a system and the amounts of matter and energy coming to the system or released into the environment. The regulatory functions in natural systems are executed by their own size H related through positive and negative feedbacks with the process of matter and energy supply in such a way that as H increases, the amount of supplied energy decreases.

It is important to note and emphasize that similar principles of functioning are inherent in the evolution of social-economic systems as well. In these systems, the size also plays the regulatory part in evolution. In other words, social-economic systems, while evolving, grow in accordance with the available ordered, negentropic flux of resources from the environment – natural and that formed by the global set of systems.

Nevertheless, only those social systems can be classified as self-organizing, whose evolution is accompanied by the increase of their own structural order and $dS \to 0$. Apparently, only such a system can be thought truly progressive. However, according to the laws of thermodynamics, in a closed system (the Earth), the evolution of social systems with unlimited growth of matter, energy, and information consumption and the increase of their size and variety surely increases the entropy of the systems forming the environment. Thus, we come to a seemingly paradoxical conclusion: civilization as a whole is not a self-organizing system.

In fact, the evolving self-organizing natural systems do not increase the entropy of the Earth's ecosystem. A sufficient body of data suggests that they decrease the entropy, thus increasing the possibilities of stable evolution. Every time when evolution of natural systems was broken by global catastrophes, the Earth's ecosystem not only regenerated, but developed toward the state of teleological functional order. This process is possible in only one case: when the system (in this case, geoecosystem) receives energy, matter, and *negentropy*, i.e., something that contains and carries the order, from the environment. The civilization, according to the inherent principles of self-organization and functioning, which assume its motion to a stable, dynamically equilibrium state, surely increases its own entropy and the entropy of geoecosystems.

This contradiction is neither unresolvable nor unexplainable. The current dynamic state of the civilization is a temporal one caused by some delay in development of negative feedbacks. Under close examination of current global tendencies, we can see the marked growth of various negative regulatory factors.

Spontaneous tending for equilibrium as a driving force of evolution

Following the logic of the above reasoning, we cannot pass over the widely discussed problem on the role of the equilibrium state in the system dynamics.

It is believed[8,9,31,32] that bifurcations and chaos are the decisive factors in evolution of holistic systems, while the objective tendency to equilibrium characterizes the increasing degradation of a system. And now there exists a tendency to understand bifurcations as "turning points of evolution," the selection of some further way of evolution under the effect of slightest random factors. Bifurcations are also often associated with the sensitivity to the initial conditions and formation of the so-called strange attractors described by Lorentz in 1963. It is necessary to warn against a significant, in our opinion, error – hypertrophied overestimate of the role of bifurcations and the initial conditions of evolution of complex self-organizing systems. In mathematical models of system evolution, it is possible to digress from actual situations and, varying some decisive parameters, come to the conclusion about the role of a butterfly wing flap in evolution of complex systems. Abstract mathematical models of formation of strange attractors and deterministic chaos provide the fundamental background to the well-known ideas of Hayek and other economists on the impossibility to predict the evolution of complex systems, such as, for example, social-economic ones. Taking a great interest in abstract mathematical models, scientists often ignore the facts and theory of cybernetic systems and automatic controlling systems.

All complex self-regulating and self-organizing systems evolve rationally, what is their immanent property. A man creates various technical systems: airplanes, rockets, satellites, etc. These systems move in accordance with the given aim to reach the target. They all are sensitive to initial conditions, and from the very beginning their given and current trajectories begin to differentiate, but this difference is suppressed by a continuously acting regulator correcting the system trajectory. If this were not possible, then the humanity would never achieve the vast progress it has achieved now. Flocks of migrant birds also would never reach their destinations, if they were not able to correct the way in accordance with the given state.

For the systems with developed negative feedbacks, the chaotic dynamics is not a feature, what, generally speaking, is confirmed by the presence of stable fractal regularities showing themselves in both the form (fractal geometry) and the content (fractal dynamics), for example, in the automodel mode of system evolution. The chaotic dynamics arises, in our opinion, as a result of disturbance of system hierarchy and fractal relationships, rather than because the fractal state transition naturally, spontaneously, and objectively changes into the dynamic chaos. The chaos described by mathematical models can evolve in abstract systems, if variations of coefficients (some abstract parameters characterizing the specificity of systems) go beyond the limits of natural dynamics that exist thanks to negative feedbacks. Thus, the gradual increase of the coefficient of the growth parameter in the Verhulst–Perl predator–prey model, when reaching some limited value, leads to chaotization of the process of reproduction of both the predator and prey populations.[33]

The whole set of events accompanying formation of order and chaos is indicative of the fact: coherence of particles and consistency of their motion are impossible in the state of chaos. Their synergism arises due to effects of higher rank and increases asymptotically with saturation, approaching the state of dynamic equilibrium. Only when the equilibrium establishes, all elements of the system "see" each other. Moreover, in the state of dynamic equilibrium, the mutual conditionality and consistency of the behavior of system elements are in the most perfect form as compared to the initial period of destruction of chaos and formation of order. It is quite another matter that the system undergoes most significant changes beginning from the formation of order and to establishment of the equilibrium state; these changes decrease when approaching the equilibrium and become negligibly small in the state of dynamic equilibrium. Nevertheless, in this state, the system and the environment exchange matter, energy, and information at the level sufficient to keep this state unchanged. Disagreements on these phenomena likely follow from the fact that in the equilibrium state it is rather difficult or even impossible to find the dynamics of the transient behavior from chaos to order and from order to chaos. However, it should be recognized that the state of equilibrium for all self-organizing systems is an attractive aim or a given state in technical systems.

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