Synergetic modelling of sustainable development

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This paper deals with the generalization of the problem of sustainable development, the concept of which is based on the assumption that societies need to manage three types of resource (economic, social, and natural). The field of sustainable development can be conceptually broken into three constituent parts (subfields): environmental sustainability, economic sustainability and sociopolitical sustainability. The analysis of sustainable development history in recent years shows that synergetic balance between the subfields represents a necessary condition for sustainability, the fulfilment of which depends on the entire policy. The problem cannot be solved without a systems approach, such as living systems analysis, synergetics, system modelling or complexity theory. The role of system sciences is increasingly determined from the viewpoint of behavioural modelling of the most complex system. In general, development represents system building in dynamics, but sustainability is associated with stability of the system. On the other hand, any system's degree of development can be defined as a function of complexity, including diversity. In general usage, complex systems tend to be high-dimensional, nonlinear and hard to model. Structurally sustainable development represents the treelike structural genesis of system fractals (or clusters); i.e., the hierarchy of epistemological levels, every level of which corresponds to the degree of system dimension. At the same time, at any level, the system may be considered in just two aspects: horizontal (epistemological) and vertical (hierarchical). The more complex the system (including the possibility of a multilevel structure) the more developed it is. In this paper, we present a new approach for a formal description of the complexity with respect to the viewpoint of modelling and sustainability, conditioned by the existence of nonlinear environmental, economic or other natural factors. Contemporary system models are more likely to be nonequilibrium models emphasizing the concepts of entropy and synergy. The originality of this work lies in the description of system as a form of

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quantum graph with synergetic edges as a superposition of fuzzy entropy and synergy. Diversity is conditioned by system homeostasis or heterostasis. In any given context, during a developmental processes in dynamics, the achievement of unity of clusters can be realized, when pairs of system clusters unite to form new single clusters, which provokes redistribution of the synergy/entropy, its balance and increasing fitness.

Keywords: entropy, modelling, sustainable development, synergy

1. Sustainable development as such

Generally sustainable development is a pattern of resource use that aims to meet human needs while preserving the environment so that these needs can be met not only in the present, but also for future generations. This has become the most often-quoted definition of sustainable development, which ties together concern for the carrying capacity of natural systems with the social challenges facing humanity. The field of sustainable development can be conceptually broken into three constituent parts: environmental sustainability, economic sustainability and sociopolitical sustainability.

The Universal Declaration on Cultural Diversity[1] further elaborates the concept by stating that "...cultural diversity is as necessary for humankind as biodiversity is for nature"; it becomes "*one of the roots of development understood not simply in terms of economic growth, but also as a means to achieve a more satisfactory intellectual, emotional, moral and spiritual existence*".

The concept of sustainable development does not focus solely on environmental issues. Environmental sustainability is the process of making sure that current processes of interaction with the environment are pursued with the idea of keeping the environment as pristine as naturally possible based on ideal-seeking behaviour. Sustainability requires that human activity only uses nature's resources at a rate at which they can be replenished naturally.[2,3] Inherently, the concept of sustainable development is intertwined with the concept of carrying capacity. Theoretically, the long-term result of environmental degradation is the inability to sustain human life. Such degradation on a global scale could imply extinction for humanity. The sustainable development debate is based on the assumption that societies need to manage three types of capital (economic, social, and natural), which may be non-substitutable and whose consumption might be irreversible.[4]

The concept of sustainability tries to represent a moving and adaptable response to networks of theoretical, methodological and practical questions, related to connexions, interrelationships and interactions within and between a series of couplets that firmly link (or separate) the intelligibility of our world, human solidarities, biosphere unity, and the efficiency of social activities. Practically, sustainability in development brings up the qualitative and quantitative problems around energy and raw material flows and storage, either picked up or

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1 UNESCO Universal Declaration on Cultural Diversity (2001).

2 Arrow, K.J., Dasgupta, P. and Mäler, K.-G. Evaluating Projects and assessing sustainable development in imperfect economies. *Environmental and Resource Economics* **26** (2003) 647–685.

3 Arrow, K.J., Dasgupta, P. and Mäler, K.-G. The genuine saving criterion and the value of population. *Economic Theory* **21** (2003) 217–225.

4 Dasgupta, P. and Mäler, K.-G. Net national product, wealth, and social well-being. *Environment and Development Economics* **5** (2000) 69–93.

emitted; it does not dissociate ethical and normative solidarity, neither horizontally with the impoverished nor vertically between successive generations.[5]

The sustainability concept invites us to consider the systemic interrelationships and to engage within the scope of a framework taking into account a holistic methodological structure in which the affirmation of world unity implies its diversity and also requires us—concerning human society—to recognize the specificity and degrees of freedom of this diversity, and to develop solidarities that are conditional to its own reproduction. Principles of sustainability assume circulation, transparency, crossing and stimulating synergism of information, both upwards and downwards.

The holistic structure of sustainability encompasses (and rebuilds qualitatively, in the mode of systemic conciliation): scientific knowledge, without separating parts during the rebuilding; ethics; and the scientific approach. An economy of solidarity characterized by social capital, which concerns information and its production in a social context and is in possession, together with industrial ecology, of one of the other keys of sustainability: territory-based associations of inhabitants acting for themselves, appears as an essential vector of local sustainability and of novel tasks for implementing global sustainability. Implementation of sustainable development implies core principles of individual action and social responsibility.[6] It requires a transversal circulation of information, compels a rebalancing of the order of importance of the three poles characterizing economic rationality: market, plan and reciprocity, by insisting on the supremacy of the last one, reciprocity.

2. Sustainability through synergy

This section focuses on a new approach towards a formal description of complexity with respect to the viewpoint of modelling and sustainability conditioned by the existence of nonlinear environmental, economic and natural factors.[7–9]

It often appears that there are several contradictions between environmental, economic and sociopolitical sustainability. If we consider any of them as consisting of multiple interacting agents, sustainable development can be associated with its complexity, which corresponds to the degree of system dimension and diversity of objects (from the viewpoint of modelling).

Agents interact (communicate, coördinate, negotiate) with each other and with their environment. Usually, in a multi-agent system, interaction dynamics between an agent and its environment lead to emergent structure or emergent functionality. Structurally, multi-agent systems represent a hierarchy of epistemological levels, every level of which corresponds to a degree of system dimension and complexity.

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5 Ehrlich, P.R. and Goulder, L.H. Is current consumption compatible with sustainability? A general framework and some indications for the United States. *Conservation Biology* **21** (2007) 1145–1154.

6 Hamilton, K. and Clemens, M. Genuine savings rates in developing countries. *World Bank Economic Review* **13** (2004) 333–356.

7 Georgescu-Roegen, N. *The Entropy Law and the Economic Process*. Cambridge, Mass.: Harvard University Press (1971).

8 Ramsden, J.J. and Kervalishvili, P.J. (eds) *Complexity and Security*. Amsterdam: IOS Press (2008).

9 Kervalishvili, P. Quantum processes in semiconducting materials and spin electronics. *Rev. Adv. Mater. Sci.* **14** (2007) 71–80.

Development as a recursive process in general represents an ascending process in a hierarchy in which a transition to the upper level occurs only after formation of the lower level. At the same time, at any level a multi-agent system may be considered from the viewpoint of just two aspects: horizontal (epistemological) and vertical (hierarchical). The more complex the system is, or the more multilevelled its structure, the more developed it is. Hence, sustainability of development as system complexity is a function of diversity (functionality) and dimensionality.

Let us briefly outline some nuances of development. The study of sustainability is still in its infancy. Yet, it already provides us with a powerful new perspective and a number of promising conceptual and modelling tools for understanding the environmental phenomena that surround us, including organisms, ecosystems, markets and communities. Any change or evolution of the system can be described as a transition from one state to another, which is closely related with the changing of entropy. In thermodynamics, entropy is often associated with the amount of order, disorder or chaos in a thermodynamic system. A property frequently used to characterize development is an increase or decrease of order (disorder) and the intuitive notion is to identify that with the entropy. We can imagine disorder as a disoriented agent's behavioural vector.

In this paper we focus on the epistemological case, hence we can consider the development optimization processes with system entropy minimization criteria.[10] The fundamental claim of this paper is the relation between development in multi-agent systems and entropic concepts such as information (Shannon) entropy. Contemporary systems models are more likely to be nonequilibrium models emphasizing the concept of entropy. Entropy has a number of advantages over equilibrium for a system. It has led to the development of a number of models using entropy, including Shannon information theory, synergetics and complexity theory.

As regards synergy (also called synergic or synergistic science or synergetics), it means that wholes have properties (functional effects) different from those of the parts. Without synergy, there is no complexity, no adaptation, no development and no life.

Nature provides infinitely many examples of emergence and evolutional development. One of the evident examples is the evolution of biological organisms, when functional creatures were formed from unicellular microörganisms. The first cells were antagonistic to each other due to the self-survival instinct. But, in the struggle for existence weak homeostasis failed to save them. As a result unicellular colonies appeared in the evolution process. They created a so-called population having collective homeostasis in the case of interest coincidence on the bases of social heterostasis. When the stability of the system cannot be restored, then it calls for external help. Only those species survived that could adapt, overcome egoistic instincts and adopt social heterostasis. In the given context, the criterion of societal security is associated with stability, and from a biological viewpoint with the idea of homeostasis or fitness function.

This example may appear too specific to support our argument. Nevertheless, the collective behaviour of agents or clusters in different environmental conditions can be formalized for modelling evolutionally developing systems.

[10] Janelidze, G. and Meparishvili, B. Evolution algorithm of multiextreme optimization. *Intelecti* **1** (2006) 119–121 (Tbilisi).

3. Synergy-based modelling approach

Every system is characterized by *structure, composition* and *state*. The state of a system is described by different degrees of incompatibility. At any scale social processes are characterized by acute confrontational background, therefore often proceeding at a subcritical limit of imbalance. The so called "strong" social cluster tries to increase by oppression of clusters with "weak homeostasis" and strive for a leader to prevent imbalance in the cluster. Small clusters try to seek external assistance as social heterostasis for strengthening their own homeostasis.

In this paper, on the basis of the aforementioned preliminary studies and our current work with biological and social processes, we formulate a new approach, based on a fuzzy entropy minimization of the system.

For generalization, various approaches were introduced consistent with a new concept of entropy as an internal behavioural incompatibility (resistability) or antagonism between the agents of the system, which is related to energy consumption. We discuss conceptual and practical possibilities of such an admission, which is an important interpretation for the systems approach.

We introduce new notions based on a model of the brain, composed of neural cells in a networking system, which are activated depending on the subject's location. Such a network is made of two neuron layers (input, and output) and is usually constructed as a regular two-dimensional grid of neurons. This grid represents a topological model of the application to clusters.

Any system, including multi-agent systems and their components, can be considered as a so-called "synergic graph", where an agent corresponds to a "neuron". For convenience, let us define a synaptic graph to correspond to the topological model of any complex system; i.e., an axon–dendrite model with synaptic connexions between them. Formally, axon–dendrite models can be represented in the form of a graph:[11, 12]

$$B = \{b_i\},\ i = \overline{1, N} \tag{1}$$

with "dendrites" as the set of system requirements (needs) and "axons" as the set of possibilities. The neuron can be represented in the following form:

$$b_i = \{t_{ik}\},\ k = \overline{1, L}\,. \tag{2}$$

Generally, each axon or dendrite can be described as a terminal:

$$t_{ik} = \{s_{ik}, d_{ik}, \omega_{ik}\} \tag{3}$$

where $s_{ik} \in \{-1, +1\}$ is the sign of the terminal, $d_{ik} \in D$ is the type of the terminal and $\omega_{ik} \in [0, 1]$ is the weight coefficient of the terminal. The total number of terminals is

$$Q = \sum_{i=1}^{N} \sum_{k=1}^{L} t_{ik}\ . \tag{4}$$

The connexion between neurons is realized by synapses:

[11] Meparishvili, B., Gachechiladze, T. and Janelidze, G. In: *Complexity and Security*, pp. 379–388. 2007, ISSN 1874-6276.

[12] Kervalishvili, P. and Meparishvili, B. Molecular Machines Modelling Approaches. *ERA-2 Proc. the Contribution Of Information Technology Science, Economy, Society and Education*. T.E.I. of PIREAUS: 453–460 pp. 2008.

$$C_{ij} = \{t_{ik} \circ t_{kj}\} \tag{5}$$

where ∘ represents the synapse or cohesion. Each synapse is established under the conditions:

$$C_{ij} = \left\{ (s_{ik} = -s_{kj}) \wedge (d_{ik} = d_{jk}) \wedge (|\omega_{ik} - \omega_{jk}| = \min_k) \right\} \tag{6}$$

where $s_{ik} = -s_{kj}$ is the polarity of terminals, $d_{ik} = d_{jk}$ is the identity of types, $|\omega_{ik} = \omega_{jk}| = \min$ is the minimum difference of weight coefficients, which actually determines the degree of incompatibility, and ∧ is a special symbol (the *conjunction)* that connects the conditions.

Let us consider the environment as a virtual element of the system. The weight coefficients for all its terminals will be $\omega_{or} = 0$, where $r = \overline{1, F}$, R being the number of synapses (R = card$\{C_{ij}\}$, where card means the cardinality, i.e. the number of elements in the set of synapses); F is the number of free terminals ($F = Q - 2R$), and μ the degree of incompatibility, which corresponds to the absolute value of the weight coefficients of terminals in the synapse.

After reindexation, $(ik) \to r_{(ik)}$, and

$$\mu_{r_{(ik)}} = |\omega_{ik} - \omega_{jk}|. \tag{7}$$

Entropy H is determined by the number of ways to achieve a state and is calculated as the following function:

$$H = -\sum_{r_{(ik)}=1}^{F} \mu_{r(ik)} \log \mu_{r_{(ik)}} - \sum_{r_{(ik)}=1}^{R} P_{r_{(ik)}} [\mu_{r_{(ik)}} \log \mu_{r_{(ik)}} + (1 - \mu_{r_{(ik)}}) \log(1 - \mu_{r_{(ik)}})] \tag{8}$$

where P is the probability of the event $r(ik)$.

System behaviour is determined in the area of external and internal freedom. Compatibility of the synapses is the necessary condition for synaptic graph unity.

Generally, a model of the system is a multidimensional graph, where the degree of dimension is defined by the number of types of terminals. We can consider a cluster as a subgraph or projection of the graph on any type of terminal. Hence, the graph is the set of clusters.

Synergy of the graph, on its part, is the function:

$$S = \log \sum_{i=1}^{n} \mu_i - \sum_{i=1}^{h} p_i \log p_i \tag{9}$$

where h is the number of orbits of isomorphic groups and p is the probability of the orbits of isomorphic groups.

Based on quantum theory, the fuzziness of each synapse is determined like the entropy and information, namely by the quantum probability of entropy–synergy superposition. System stability or homeostasis at a given epoch is determined as the difference between synergy and entropy:

$$M_h = S - H. \tag{10}$$

As a result of the synapses the merging of neurons takes place and a new ensemble consisting of a synergic–entropic union is created.

We can consider this phenomenon as clustering. Every synapse or interaction between any two (or more) clusters recursively forms the new entity (i.e., the new united cluster), which has mutually modified or forced redistribution of synergy–entropy, its balance and its fitness (homeostasis). Creation occurs when entropy converts into synergy and vice versa, when breaking up synergy converts into entropy. The clustering processes generally can be realized in the following sequence: *Confrontation* → *Coöperation* → *Consolidation*. Three forms of agent interaction are determined:

Confrontation caused by antagonism of interests between subjects:

$$\text{when synergy} < \text{entropy and } \sum_{i=1}^{n} \mu_i > 0;$$

Coöperation or collaboration (low degree of heterostasis) conditioned by coincidence of interests between subjects in the case of internal antagonism:

$$\text{when synergy} > \text{entropy and } \sum_{i=1}^{n} \mu_i > 0;$$

Consolidation or harmonious coexistence (high degree of heterostasis) which is conditioned by coincidence of interests between subjects without any internal antagonism. This is an ideal case of social state:

$$\text{when synergy} > \text{entropy and } \sum_{i=1}^{n} \mu_i = 0.$$

Hence, sustainable development through synergy can be realized in the following sequence:

Confrontation → *Coöperation* → *Consolidation*.

These are the destructive (antagonistic) and beneficial (coöperative) interaction forms. The very essence of any synergistic behaviour is that the two parts both benefit, and in larger systems all participants should benefit. In each given case, the realization of the various versions of optimization is possible by the criterion of stability maximization.[13]

4. Conclusions

The field of sustainable development can be conceptually broken down into three constituent parts: environmental sustainability, economic sustainability and sociopolitical sustainability. It often appears that there are several contradictions between environmental, economic or sociopolitical sustainabilities. Hence, we can consider them as multiple interacting agents.

Sustainable development can be associated with its complexity, which corresponds to the degree of system dimension and diversity of objects from the viewpoint of modelling.

Using mathematical formalism we have elaborated a new approach, which is based on the use of a so-called "synergic graph", which represents the topological model of any complex system; that is, the axon–dendrite model with synaptic connexions between them. System stability or sustainability at a given epoch is determined as the difference between synergy and entropy.

[13] Kervalishvili, P., Meparishvili, B. and Janelidze, G. Artificial intelligence: problems and prospective. *Summary Proc. 2nd CODATA International Conference on Scientific Information for Society—From Today to the Future*. Kyiv, Ukraine, NTUU-KPI, October 2008.