Computing Anticipatory Systems: Proceedings of the Ninth International Conference on Computing Anticipatory Systems, edited by D.M. Dubois, AIP Conference Proceeding, Melville, NewYork: American Institute of Physics, 2010, V. 1303. P. 297-306.

Bootstrapping of Life through Holonomy and Self-modification

Alexander B. Kazansky

I.M.Sechenov Institute of theEvolutionary Physiology and Biochemistry
of the Russian Academyof Sciences
Torez avenue,44, St.Petersburg, 194223, Russia be indicated by superscript
e-mail: kazansky@bk.ru, http://akazansky.by.ru

Abstract. Life on the Earth demonstrate not only adaptive, cognitive, particularly, anticipatory properties, but also active, transformative function to its local and global environment. As V. Vernadsky stated, life is a powerful geological force. Charles Darwin realized that too. In his last work [1] he proved, that earthworms through their vital activity in geological time scale are able to form and support contemporary structure of soil on the whole planet. Locally, through so-called process of niche construction [2] organisms virtually modifies abiotic and biotic factors of natural selection and thereby insert feedback loop in evolutionary process. Stigmergy [3] is one more form of indirect interaction of organisms via the environment by signs, left in local environment or just by performing working activity in swarms, leading to self-organization and coordination of actions in the process of refuges construction. In organization of life we can separate active, rigid, organism-like, autopoietic-like systems or less rigid, sympoietic, socio-biological type systems [4]. Nevertheless, all forms of life systems demonstrate so-called bootstrapping, or spontaneous process of self-organizing emergence. This process is feasible thanks to self-modification, and holonomy in their organization, or total reflexivity. Analysis of the role of indirect interactions in bootstrapping, made in this paper, is aimed at revealing relationships between concepts and making step to forming new systemic model of organization and evolution of special dual pair, biota and biosphere.

Keywords: bootstrap, holonomy, self-modification, niche construction, biosphere.
PACS: 87.18. –h; 87.18.Vf; 89.75.Fb

1. INTRODUCTION

Biological and human systems, the biosphere often embody the most radical and not always successful ideas and models of physicists, engineers and philosophers.

Holonomy, not in a strict specific mathematical sense, but in a wider understanding of physicist David Bohm [5, 6] as a holonomic (sometimes called holographic) systemic paradigm seems more applicable nowadays to biology then to physics. Indeed, every cell contains genome of the whole organism. Animals, from primitive organisms up to Homo sapiens demonstrate increasing reflective and modeling abilities. Opening of so-called mirror neurons, firing under imitating behavior [7] is one more serious argument in favor of that. World Web user has access to huge volume of information about everything. Slogan of holonomic paradigm is “all contains all” and the symbol — Buddhist God Indra’s Net of Pearls, when all pearls are reflected in each one.

The same successful destiny waited bootstrap, term, first used in physics by Geoffry Chew [8] as a name of his model of hadron’s collective self-consistent particles co-existence. The more general version of the idea is that the universe is a self-consistent web of interrelations, not particles. The term is now widely used in many fields of science, mathematical statistics, business, politics, arts, etc. In some sense, physical bootstrap of Chew is closer to the concept of holonomy. What most people have in mind with bootstrapping is a spontaneous process of self-

organizing emergence, in which life is avowed champion. Individual development and evolution are just synonyms of collective bootstrapping of cells and organisms accordingly.

Self-modification, [9] is one of the most universal characteristics of life activity, from niche construction concept [2], when biological populations transform their local environment thereby changing its evolutionary selective characteristics, to global transformative role of biota in biosphere evolution, where life, according to V. Vernadsky [10] is outstanding as a "powerful geological force".

Stigmergy [3] is the kind of indirect interaction of organisms via environments. Environment play role of notebook, in which biological organisms leave records in a form of pheromones or other markers, and thus send messages to each other. So, we can say, that biological organisms communicate by perturbing semiotic characteristics of the environment, semiosphere.

If we add still debatable models of autonomy, or organizational closure in the form of close systemic concepts of autopoiesis with enactivism [11, 12], self-organizing hypercycles of M. Eigen and P. Schuster [13], component system of G. Kampis [9], model of metabolic — repair (M,R)-system of R. Rosen [14, 15], we'll get well, list of the most popular themes for discussions of those who endeavor to formalize evolution of complexity in biosphere.

Of course, there is also a territory of biosemiotics [16, 17, 18], still poorly integrated into operational models and which is closely related with mentioned above stigmergy and other types of animal communications.

As far as life systems demonstrate behavior, which we apt to construe as cognitive, all that is true for life, is true for cognitive systems in general — artificial or natural. Adaptive and anticipatory behavior are attributes of robots and living systems. Specifics of life processes as distinct from mechanical systems is that all mentioned above aspects of behavior or structure are closely interrelated. It is the cognitive approach to biological systems, that helps to surmount fragmentation and come to integrative, more adequate models of life.

Strongly anticipatory systems, by definition [20] not only make prediction of its environment, but continuously reconstructs its own configuration and structure of the environment. But, that is really, undeniable characteristics of life itself.

This work is an endeavor to reveal some relationships between holonomy (in sense of holistic system paradigm), bootstrap (self-emergence) and transforming to environment as well as self-modifying abilities of live. The aim of these reflections is to outline some general features of future metamodel of life, as a planetary phenomenon where biosphere is considered as a special creative environment with its specific meta-systemic properties.

2. INDIRECT INTERACTIONS IN ECOSYSTEMS

Generally known types of indirect interactions via environment in ecology and/or evolutionary ecology are niche construction and stigmergy, realized through modification by organisms of physical or semiotic characteristics of local environments, ecological niches, biotopes.

The behavior of organisms is shaped by the environments to which they must adapt. But their behavior can often shape the environment in return, altering the selective forces that operate on behavior. These co-adaptive loops are found in a variety of contexts, from social insects building the physical spaces in which they live, to populations of communicating agents creating the language they must learn, or groups of web users influencing the structure of the website networks they navigate.

2.1. Niche Construction

Odling-Smee, Laland and Feldman define niche construction as follows:

"…Niche construction occurs when an organism modifies the feature-factor relationship between itself and its environment, either by physically perturbing factors at its current location in space and time, or by relocating to a different space-time address, thereby exposing itself to different factors" [2, p. 41).

Organisms do things that have feedback consequences and these consequences in turn alter the designs of the organisms themselves, or of others. (Fig. 1). Niche construction takes place at all taxa, but especially, among animals, that constructs nests, holes, burrows, webs. Sometimes, niche construction activities are also relate to chemical characters of milieu.

The model of Odling-Smee et al. (Eq. 1–2) accounts for the effect of niche construction. Evolution is the process in which population O_p and its local environments E_p co-evolve, co-construct each other. The initial model includes also expression, describing influence on co-evolution of global environment parameters E, which do not depend on population activity [21]. As far as this expression is just qualitative and was not correctly formalized, it is not given

here. But, really we should realize, that system is not closed and non-controlled by organism part of the environmental parameters can effect in complex manner directly and indirectly population and its niche.

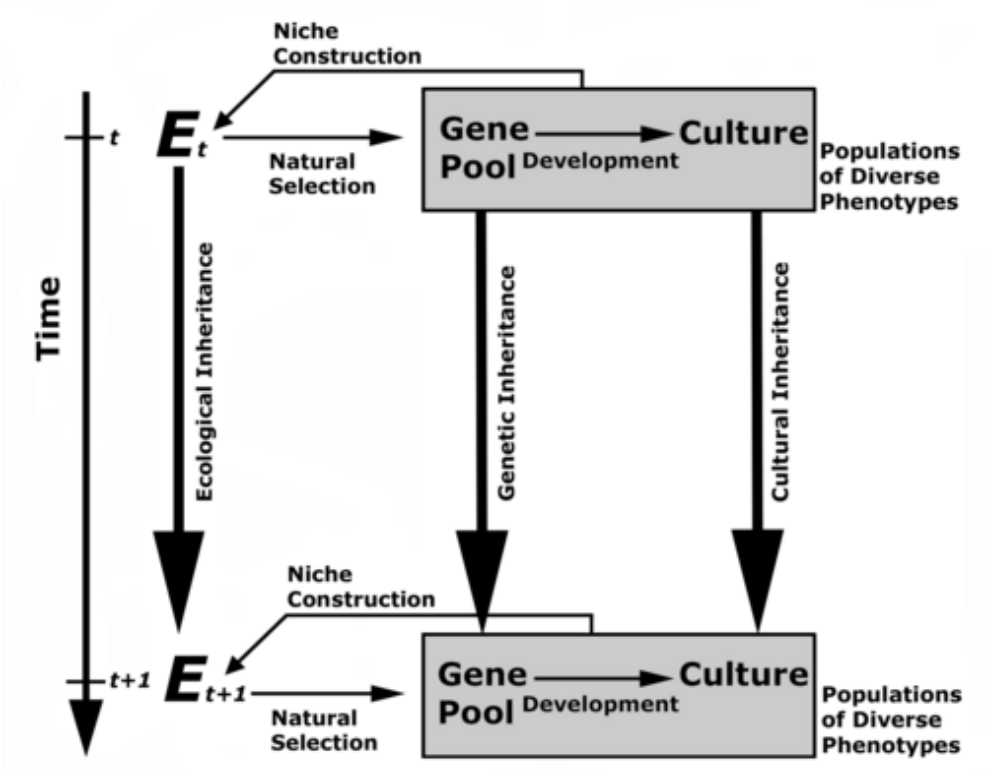

FIGURE 1. The niche construction or triple-inheritance model of bio-social evolution. In contrast to the standard model of neo-Darwinian evolution, this extended framework also recognizes cultural as well as ecological inheritance as important tiers of human evolution. Cultural inheritance specifically refers to knowledge, skills and artifacts that are in effect personal, whereas ecological inheritance encompasses modification of the ancestral environment that are bequeathed onto the next generation, as well as communally held aspects of culture. (Redrawn from Laland et al., [22, p. 136]).

$$\frac{dO_p}{dt} = g(O_p, E_p), \tag{1}$$

$$\frac{dE_p}{dt} = f(O_p, E_p), \tag{2}$$

where O_p — population of organisms; E_p — organism-referent environment of a population; g, f — functions.

Following these equations, populations of any species are an outcome of traits of prior populations plus traits of local environments. Local environments are an outcome not only of previous local environments, but also organisms, that occupied them.

For example, the action of earthworms during burrowing causes major changes in the physical and chemical structure of the affected soil. This has numerous effects, including facilitating greater plant growth, which in turn benefits the earthworms in terms of increased plant debris to consume. Such effects may take many generations to become established. It is also probable that earthworm epidermal structures and the amount of mucus secreted has changed over time as these other effects took hold — for burrowing through the soil has become a different task thanks to long-term worm behavior. So, here we see the actions of earthworms creating an environmental niche —

namely, a specific soil type — and this in turn feeds back to affect the worms such that their environment is improved and their phenotype modified in light of these changes.

It is worth noting that niche construction can affect future generations, as in the earthworm case, or the current generation, as well as individuals or groups. What is more, it can affect other species too, as has happened for a variety of plants in the earthworm example, and it can also have knock-on effects for other neighboring ecosystems. In short, organismic action can have effects at multiple levels and at multiple loci.

Darwin was well aware of the reciprocal influence of organism and environment and conducted pioneering studies on the role of earthworms in the formation of soils [1]. With great analytical insight, Darwin calculated the tonnage of soil turnover per acre that worms bring about and he speculated on the long-term effects that these activities had on the physical appearance of the landscape. “I was thus led to conclude,” he writes in the monograph, “that all the vegetable mould over the whole country has passed many times through, and will again pass many times through, the intestinal canal of worms.” In the book’s final paragraph, he concludes, “The plough is one of the most ancient and valuable of man’s inventions; but long before he existed the land was in fact regularly ploughed, and still continues to be thus ploughed by earthworms. It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly organized creatures.”

To the authors of Niche Construction conception, genes, minds and societies are all involved in various forms of co-construction. They state, that a better understanding of life requires that we abandon the view that organisms are account books recording in their behavior past ages of the Earth and see them rather as builders engaged actively in the planet's construction.

Of course, the model of niche construction given here (Eq. 1, 2) is a great simplification of real situation. In reality, organisms have complex life cycles and different niches at different developmental stages. That is why, niche construction theory combine now with the so-called “developmental system theory” (DST) [21]. Indirect, mediated by environment interactions often play crucial role also in macroevolution [22] and evolution of ecosystems. Virtually, these themes are aspects of ‘Holistic Darwinism’, arising post-Neo-Darwinian evolutionary paradigm [23].

2.2. Stigmergy

The term stigmergy was originally coined by Grasse [3] to describe the processes which lead to the formation of termite mounds. Virtually, it is a form of communication where signs left in the environment later affect the behavior of others, who met this sign. Termite mounds achieve their complex cathedral-like structures because termites bind lumps of mud with pheromone-laced saliva and are more inclined to drop lumps where the scent of pheromones is strongest. In a result, this leads not only to clusters of mud piles which grow upwards, but also to the towers so-formed to grow towards each other, creating complex arches and ornate structures.

The same kind of process leads to ant trails. Ants wander aimlessly until they find food, after which they return to the nest leaving a trail of pheromones. Other ants encountering a trail of pheromones are likely to follow it. If they too find food, they too will return to the nest with it, leaving their own pheromone trails. The cumulative pheromone trail becomes stronger and stronger, attracting more ants from further field. The system continues on this positive-feedback loop until the food runs out, after which the pheromone trail fades. A significant feature of this process is that trails inevitably form along the shortest paths to the largest and/or most accessible source of food. Like the formation of termite mounds, stigmergy thus results in a kind of collective intelligence and self-organization.

The same process underlies many human activities. For example, stock exchanges and money markets exhibit similar qualities, where money or stocks act as signs for others to invest, strengthening the signal so that still more others follow. If all else is equal, stock, share and currency prices are self-adjusting and not the product of individual plans. The most that can be done is to influence their behavior, not to determine it.

Stigmergy as a special mechanism of indirect sign communication of biological organisms is the aspect of biosemiotics, young science, which study informational, sign processes (semiosis) in biological and ecological systems. Biosemiotics in its turn is related with zoo-psychology and cognitive science in general. Sign, informational as well as cognitive processes are inherent to organization of all living systems and are instruments of all types of anticipatory behavior.

Founder of biosemiotics von Uexküll [16, 24] developed conception of Umwelt, a phenomenal semiotic subjective world of animal, sign model of its environment, space of subjective signs, generated by any animal. Animals use this subjective model to anticipate and foresee events, to communicate with other individuals, to orient and to survive in the world. Organisms together construct semiosphere [17, 25], common semiotic space, a set of interconnected Umwelts. Semiotic relationships can evolve as any other evolutionary traits.

Informational aspect of organisms' transformative activity deserve special analysis and is not considered here, nevertheless, constructivist paradigm of semiosphere concept worth attention. It is an analog of the conceptual cybernetic constructivist model of life, proposed in present work.

3. VERNADSKY'S BIOSPHERE, AND LOVELOCK'S GAIA: GLOBAL EFFECT OF INDIRECT INTERACTIONS

V. Vernadsky gave a thorough definition of the biosphere [10]. The biosphere, according to Vernadsky is an envelope of life, the area of existence of living organisms. At the same time, biosphere by Vernadsky is a self-regulating system, including both living and inert constituents. The work of living matter in the biosphere is manifested in two main forms: chemical (biochemical) and mechanical. Vernadsky made a detailed analysis of different forms of biochemical and mechanical transformative to environment activities of life and realized, that there is no force on the face of the Earth more powerful in its results than the totality of living organisms. No phenomena in the biosphere are separated from life and biogeochemical cycles. To analyze these processes, Vernadsky introduced the notions of "living matter" of the biosphere — the sum of its living organisms, "inert matter" — non-living substance and their organic composition — "bioinert matter". Last concept is of special significance in context of self-modification and indirect interactions in ecosystems. Vegetable mold is an example of bioinert matter. Great many living forms permeate this soil and organize it. Biological activity of organisms constantly modify this environment, and thus modify organisms themselves, forming self-organized self-modifying system. Vernadsky noticed, that bioinert matter have unusual physical properties. But indeed, vegetable mold being open system, demonstrate some properties of living tissue. Soil at the same time is a special environment, organic constituent part of biosphere.

Meanwhile, tutor of young Vernadsky at the St. Petersburg university was V. V. Dokuchayev, founder of Russian soil science. In 1883, soon after the publication of Charles Darwin on the role of worms in forming vegetable mold, Dokuchayev gave a scientific definition of soil, as an organic whole, which is not outdated.

Vernadsky's ideas are very actual now in the light of progress of the Earth System Science and great interest to the role of life in global climate regulation. James Lovelock in his Gaia hypothesis virtually concentrated on this aspect of biosphere self-regulation.

Gaia hypothesis [26] suggests that not only do organisms affect their environment, they do so in a way that regulates the biosphere global climate to conditions that are suitable for life. Gaia phenomena include the regulation of local climate by marine algae that influence the formation of clouds over the oceans, global temperature regulation by biotic enhancement of rock weathering, the maintenance of constant marine salinity and N:P ratios by the aquatic biota etc.

Biosphere or Gaia, which are virtually synonyms nowadays, can be represented as a very specific, dynamic, constantly self-modifying, multilevel evolving system, composed of living, inert and bioinert components, which dynamically exchange. Wholeness of this system is provided by the dynamic interrelatedness of all components, participating in metabolic processes, local trophic cycles, local and global biogeochemical cycles. Living biological components fundamentally differ from inert, non-living components. The former are active and goal-seeking systems, demonstrating wholeness and relative autonomy. The later are passive, submit to the influence and do not demonstrate autonomy and wholeness; their dynamics is controlled by physical forces and activity of biological organisms. But, bioinert matter with high concentration of symbiotically related biological organisms of different taxa, like a vegetable mold demonstrates an intermediate properties, and that is true for the whole biosphere.

Biosphere functioning, which includes processes, proceeding in a small time-scales do not differs principally from the process of biosphere evolution, noticeable in geological time-scales. Even in the first case we cannot apply model of Markov process, reducing the role of previous history to the parameters of current state of the system. First of all, this state is unmanageable, because it should also include for example, non-coding sequences of genome (transposons, etc.), which are a potential source of innovation. Biosphere functioning as well as biosphere evolution is a creative, developmental process. In the process of biosphere evolution (functioning) all biotic components participate in the process of constant self-modification, extinction (destruction) and emerging (collective, mutual production). The abiotic components are allopoietic, open systems, nevertheless, they are passive participators of biosphere processes end are subjected to biogenic and physical transformations. Biosphere is a dynamical emergent system, and its components demonstrate, as aptly coined James Brody [27], "mutual bootstrapping", both from functional and from evolutionary points of view. Biogeochemical cyclic processes in biosphere are self-organized and provide for sustainable development.

The only absolutely autonomous, self-constructive, self-modifying and self-constitutive system on the Earth is the whole biosphere, though it is occasionally subjected to perturbations caused by collisions with cosmic objects. Apart from biosphere as a whole, all biological organisms and super-organismic systems, components of biosphere are ajar, semi-autonomous, more or less sustainable vortexes of life in biogeochemical substrate. Though biological systems have some form of autonomy, they urgently depend on each other directly, through trophic and other classical ecological relationships, but also indirectly, via environment. The organisms interacts with all components, which also interact with each other, and the nature of this interaction determines the selection pressure it experiences. Species evolve, it is possible that selection may occur on their environment-altering traits so that traits are favored, which change the global environment in some beneficial for living organisms way. Such reflections stimulate modeling experiments, demonstrating possibility of Gaia effect [28].

4. BOOTSTRAP AND HOLONOMY

As was mentioned above, bootstrap, the metaphor originated from English saying "To pull himself up by his own bootstraps" changed its meaning in different contexts, but that only favors popularity of this term. Different meanings of the word are thoroughly considered in Wikipedia and in many special reviews. In general sense, it is a spontaneous process of self-organizing emergence. Bootstrapping describes any operation which allows a system to generate itself from its own small well-defined subset without external help.

The idea of bootstrapping is creative in a number of fields in the biological sciences. Process of individual development of the organism, by which a fertilized ovum develops into an embryo, when the nuclear genome is expressed differently in its various cells as these differentiate, is an example of bootstrapping. Origin of life may have been bootstrap process too. Microevolution by natural selection is one more example.

Specifics of life bootstrapping (as well, as a process of computer translator designing) is that on some stage process starts modification of its basic elements and characteristics. So bootstrapping of life is always a fundamentally self-modifying process.

One more specifics is that any developmental and evolutionary process is not absolutely organizationally autonomous. At some critical developmental stages organism is very sensitive to environmental cues, which may change the trajectory of development. Organism is always in dialogue with the environment. But constructive dialogue with absolutely alien environment is impossible. Life has already constructed holonomic world — biosphere with generated by our ancestors some universal common senses in semiosphere. Autopoietic system cannot alive without autopoietic community and symbiotic biosphere. Some examples, given below illustrate these theses.

In evolving biological systems evolvability (ability to evolve) is an evolving trait because evolutionary lines with higher evolutionary amenability as a rule are lines, in which appear new adaptive traits. These adaptive traits will in its turn increase evolutionary amenability [29].

Symbiotic relations in ecosystems on the biosphere level are of global significance. Symbiotic complexes — these ajar organizations, sympoietic systems with positive feedbacks demonstrate bootstrapping [30]. Although these systems are stable against disturbances in its environment, they may be quite vulnerable to unusual, foreign disturbances, especially those, that reduces biological diversity. As a rule, this sort of disturbances are the result of human activity. Special investigations show, that every block of symbiotic complex — plant community, the microbial community and the whole ecosystem plays a seminal role in buffering against disturbance and maintaining healthy links between plants and soil [31].

The above and many other examples dismiss the illusion of existence of absolutely autonomous bootstrapping in nature. Evolution is always concurrent, coordinated process of global and local processes, global and local bootstrapping [23]. As V. Vernadsky marked, life is ubiquitous in the biosphere. All forms of life are similar in their basic characteristics — in organization of cells, genome, structure of proteins, metabolism, biochemistry. From the very origin of life on the Earth, our planet was symbiotic in which direct and indirect, via environment reciprocal interrelations were integrative factors. Every biological species evolve, but at the same time, it changes its local environment, and biota on a planetary scale changes surface of our planet.

So, bootstrapping of life is always a mutual bootstrapping, product of all living forms, using non-living components and physical properties of our cosmos. Strategy of life spreading — proliferation and generation of holonomic (in sense of D. Bohm [5]) multilevel, from cell to biosphere cosmos. Life generates meaning on all organizational levels. Only thanks to similarity, homology, analogy of holonomic systems and at the same time, due to fantastic diversity of forms, global and local symbioses are possible. We often underestimate the unity of life on

our planet and integrative role of different forms of indirect, background interaction, communication of the systems. Niche construction, stigmergy, biosemiotic processes are only some of them. Of course, coordination of organisms' behavior, their co-adaptation and co-evolution not always need in translation of meanings between Umwelts of organisms. Process of structural coupling of autopoietic systems, can lead to eigen-behavior, associated with fixed point of the sensory — motor operator [11] and as a result — to co-adaptation. But, this model implicitly imply congruence of organism and environment, because environment, biosphere is constructed by life. Holonomy means reflexivity. Holonomy and strategy of constructive spreading of life explains anticipatory properties of organisms, populations, species and higher taxonomic groups.

The role of biodiversity in evolution and ecological processes is generally known. But, it is interesting to look at it from the point of view of bootstrapping processes. Redundant diversity can generate chaos, but that is the chaos of a special sort. It is an "unstable" chaos, easily convertible into an order. It is a creative, structured, canalized chaos. Species, populations manipulate their abundance and diversity. By controlling dimensionality of their ensembles in a phase space, they can change their topological properties. Holonomy and diversity are a dual pair in bootstrapping processes.

Indirect relationships extends list of instruments of modification and self-modification of living systems, involving in bootstrapping process all components of environment.

Besides holonomy, as holistic paradigm, holonomy in specific, mathematical sense takes on special significance in circular processes with positive feedback in context of indirect interactions. Indeed, action of population, or species, constructing niches (physical or semiotic) returns back and changes species, often in unexpected way, depending on the path. It reminds holonomy, when parallel transport around close loops on smooth manifolds fails to preserve the geometrical data. This effect may favor diversification or invest into mechanism of evolutionary ratchet of irreversible growth of complexity. At the same time, this mechanism favors interspecific influences, relatedness and construction of holonomic biosphere (in the holistic meaning of the term).

5. DISCUSSION

The theory of autopoiesis [11, 12], dominating metamodel of living as a circular organization and logically closed cognitive system, a form of autonomy, appealing to self-reference, recursion and self–identification through internal metabolism-like dynamic processes was a very ambitious project. But, in a result of more than thirty years of active discussions, serious problems with the realization of this model, its applicability and universality were revealed. The phenomenology of autopoietic observer is even more problematic. It is not surprising, that Kent Palmer try to perfect this metamodel by developing reflexive variant of autopoiesis [36]. Again, reflexivity, holonomy are unavoidable aspects of complex biological and social systems.

Complexity of life is a serious challenge to our attempts to formalize processes in living systems. Some non-traditional mathematical structures such as the theory of categories, hypersets, hypergraphs, non-classical logics were proposed as a formalization instrument of paradoxical relationships of biological systems and environment. Particularly, hypersets, or non-well founded sets, which can contain itself as its element [32] were used for analysis of self-referential processes in biological systems, computer science and in General Artificial Intelligence [19, 33]. For example, Ben Goertzel [34] proposed abstract model of self-modifying population ("magician system") and realized it by means of abstract algebras over the field of hypercomplex numbers.

Kent Palmer in framework of the natural philosophical project "Non-dual science" [36, 37, 38] is developing a conception of meta-system which is complementary to the system and represents environments, ecosystems, situations, milieu or context. He construe this environment of biological and social systems non traditionally, as a design landscape out of which the systems as a whole arises and which at the same time, is the arena within which systems communicate, cooperate or compete. Concept of meta-system, which is not just environment in traditional sense, but also a creative space corresponds to basic idea of this paper — life mutual bootstrapping in holonomic world, which itself is by-product of bootstrapping. In other words, we have a creative process, when systems design and modify themselves by means of semantic feedback via environment. Close analogy — to see environment as an operating system and biological systems as computer programs, which are self-modifying and all together can modify each other. The appearance of new fields of computing — evolving hardware and biocomputing signify a first step towards application of self-modifying systems.

Kent Palmer [38] speculates, that Gaia (which is virtually, synonym of biosphere) is a special emergent meta-system, which at the same time, is a holarchy of holons [35]. Holons are systems, that are parts of the whole and are wholes themselves. The holonic systems demonstrate reflexivity. The extreme form of reflexivity have so-called

holoidal systems, in which each part functions based on an image of the whole system. An analogy of holoidal system is a hologram. Aggregative systems which are blind to the wholes that they are part of are the opposite to holoidal systems. Biosphere is seemingly, closer to holoidal system. At least, there is a plausible hypothesis that genome of every organism contain implicitly information about genomes of all other organisms. On opinion of Kent Palmer, self-design or bootstrapping through autogenesis can only be achieved by a swarm of holoidal holons that interact to produce their organization (environment) as a social collaboration. If he is right, biosphere (which with arising of Homo sapiens became 'noosphere') is a holoidal metasystem, demonstrating structure of mirror house, or God Indra's Net of Pearls (see above, in the Introduction). Hypersets can be used as a model of holon, and hypercomplex numbers allow so called mediated hypersets where elements can be members of themselves through the mediation of another imaginary in the series. The mediated hyperset just is an image of the kind of interpenetration of everything with everything as in God Indra's Net [38]. So, Gaia, or biosphere as an emergent meta-system is the candidate for David Bohm's implicit order [5].

Our classical understanding of environment in biology and ecology should be revised. Last discussions about the borders of cognitive and living systems, Extended Mind and Extended Life hypotheses, neo-Heiddegerian Artificial Intelligence [39] are closely related with the theme of indirect reciprocal relationships, extension of emergency paradigm on cognitive sciences and epistemology. Systems with mobile borders, emergency of subject — object dichotomy in the process of perception, situational structures in the models of dominant architecture of information processing in brain [40] — these features of bootstrapping systems should be realized in the future metamodel of living and cognitive systems, and the aim of this paper was just to highlight its main aspects. If we want to understand multilevel evolution of biological systems, human society and biosphere, we should relate very important aspect of biological autonomy [11, 12] with supplementary aspect of 'holonomization' of environment realized by modifying and self-modifying activity of life and humankind.

In the well-known meta-system transition theory by Valentin Turchin [41], algorithm of life spreading, development and evolution of biological complexity is presented as repetition of two - step process — duplication of original system with diversification and followed establishment of control over multiple copies. If we accept terminology of K. Palmer, this strategy really describes process of super-system transition, because meta-system is a system of higher logical type, like rules of play differ from real play. But, inclusion of environment in this scheme makes this strategy more realistic. Organisms collaboratively construct and modify the environment and in return are modified by this environment. In a result, we have process of co-construction, characterized by generation of novelty and holonomization, growth of connectedness and reflexivity of biosphere components (Fig. 2). This growth of complexity is fixed on genomic level and is possible only thanks to mechanism of evolutionary ratchet, formed by two poles – genome with its high fidelity of replication and closeness and creative, open environment. So, started by organisms cascade of transformations in the environment returns back in changed form (cf. mathematical

holonomy), but genome is saved and mediated by phenotype. Darwinian mechanism is working, but it

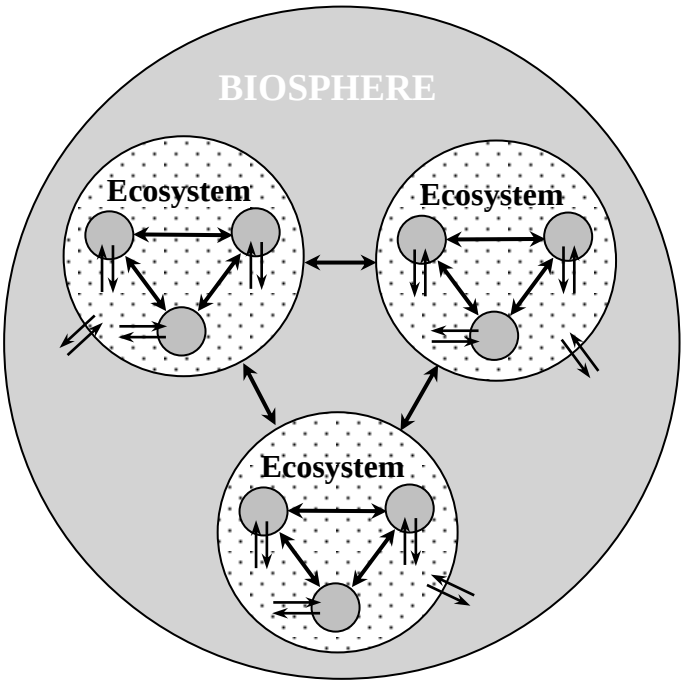

FIGURE 2. Scheme of direct and indirect (via environments) relationships of biological systems (small grey circles), which could be organisms, populations, etc. Environments — ecosystems and biosphere, which are meta-systems (see details in the text).

is not sufficient for understanding of macroevolution, evolution of ecosystems and biosphere.

Given scheme of relationships of organisms and ecosystems with their environments reminds reversed connectionist model of information processing in mind, so-called "common workspace" [44], or model of more perspective, resonance architecture [40], where the environment, metasystem play role of central nervous system. More traditional model of environment as a sympoietic system [30] does not evoke this far-reaching analogy.

6. CONCLUSION

Active role of life, which constantly transforms and directly, though unconsciously reconstruct environment in local and global scales, goes back to Charles Darwin and Vladimir Vernadsky, but only recently got due attention of the scientific community. Niche construction, ecological engineering, stigmergy are forms of indirect, via environment interactions of organisms, which often form complex networks of ecological relationships [45], overlapping on traditionally studied, direct one (e.g. trophic). Biological organisms, populations, species, ecosystems and biosphere are self-constructive, self-modifying systems. That is why, biological organisms, living and ecological systems in general are strongly anticipatory systems.

Reflexivity and modeling abilities are also attributes of living organisms. As a result, we can look at organisms and living systems in general as weakly anticipatory systems.

Bootstrapping, spontaneous process of self-organizing emergence, self-design is a useful metaphor of development and evolution of life. But, only related with reflexivity and self-modification, it has a chance to be converted into a strict scientific term in context of general metamodel of life, outlined in present paper. Specific of proposed model – more symmetrical in comparison to traditional Darwinian model consideration of the role of environment in these processes. Strategy of life expansion and evolution is realized by spreading of life in space, proliferation, collaborative construction by organisms of holonomic worlds — ecosystems and a whole biosphere. These environments are outstanding as creative landscape and an arena of interactions and constant self- and each other-modifications of biological systems. They have status of meta-systems, ("antisystems") [36].

Holonomy means here deep reflexivity and redundancy, holographic character of biosphere and semiosphere organization, co-determination and co-construction of all components, their relative and emergent nature. D. Bohm's holonomy paradigm[5, 6], Artur Koestler's idea of holon [35], G. Chew's bootstrap model [8], demonstrate basic features of biosphere and living system organization.

Holonomy and self-modification are closely related with any bootstrapping process. Niche construction, stigmergy, and other indirect, via environment, forms of interaction favors holistic view and more adequate approach to modeling of the biological, social, and informational processes [24, 42, 43, 45]. Moreover, conceptions of ecological and cultural inheritance, stigmergy opens perspective of integration of "material" ecology and biosemiotics. Traditional classical subject-object dualism of organism and environment, as a priori determined entities should be revised. Biosphere and semiosphere are mutually generated by all living forms in the constant process of mutual bootstrapping.

REFERENCES

1. C. Darwin, *The Formation of Vegetable Mold through the Action of Worms, with Observations on their Habits*, London: John Murrey, 1881.
2. J. J. Odling-Smee, K. N. Laland, and M. W. Feldman, *Niche Construction: The Neglected Process in Evolution*, New Jersey: Princeton University Press, 2003.
3. P. P. Grasse, "La reconstruction du nid et les coordinations inter-individuelles chez Bellicositermes natalensis et Cubitermes sp., La theorie de la stigmergie: essai d'interpretation des termites constructeurs", *Insect Soc*., **6**, 41- 84 (1959).
4. A. B. Kazansky, "Planetary Bootstrap: A Prelude to Biosphere Phenomenology", in: *Proceedings of the Sixth International Conference on Computing Anticipatory Systems*, edited by D. M. Dubois, AIP Conference Proceedings 718, Melville, New York: American Institute of Physics, 2004, pp. 445-450.
5. D. Bohm, *Wholeness and the Implicate Order*, Boston: Routledge & Kegan Paul, 1980.
6. D. Bohm and B. J. Hiley, *The Undivided Universe*, New York: Routledge & Kegan Paul, 1993.
7. G. Rizolatti, M. A. Arbib, "Language Within Our Grasp", *Trends in Neuroscience*, **21**, 188-194 (1998).
8. G. F. Chew, "Bootstrap : A Scientific Idea?", *Science*, **171**, 762-765 (1968).
9. G. Kampis, *Self-Modifying Systems in Biology and Cognitive Science : A new Framework for Dynamics, Information, and Complexity*, Pergamon Press, 1991.
10. V. Vernadsky, *La biosphere*, Paris: F. Alcan, 1929.
11 F. Varela, *Principles of Biological Autonomy*, New York: Elsevier/Noth-Holland, 1979.
12. F. Varela, E. Thompson and E. Rosch, *The Embodied Mind: Cognitive science and human experience*, Cambridge: Mit Press, 1991.
13. M. Eigen, P. Schuster, "The Hypercycle. A Principle of Natural Self-organization. A: Emergence of the Hypercycle", *Naturwissenshaffen*, **64**, 541-565 (1977).
14. R. Rosen, "On the Dynamical Realization of (M,R)-Systems", *Bull. Math. Biology*, **35**, 1-10 (1973).
15. R. Rosen, *Life Itself*, New York : Columbia U. Press, 1991.
16. Jakob von Uexküll, *Theoretische Biologie*, Berlin: Springer, 1928.
17. C. Emmeche, and J. Hoffmeyer, "From Language to Nature: The Semiotic Metaphor in Biology", *Semiotica*, **84**(1/2), 1-42 (1991).
18. A. Weber, F. J. Varela. "Life after Kant: Natural purposes and the autopoietic foundation of biological individuality", *Phenomenology and Cognitive Sciences*, **1(**2), 97-125 (2002).
19. D. M. Dubois, "Computing Anticipatory Systems with Incursion and Hyperincursion" in *Proceedings of the First International Conference on Computing Anticipatory Systems*, edited by D. M. Dubois, AIP Conference Proceedings 437, American Institute of Physics, 1998, pp. 3-29.
20. D. M. Dubois, "Review of Incursive, Hyperincursive and Anticipatory Systems — Foundation of Anticipation in Electromagnetism", in: *Proceedings of the Third International Conference of Computing Anticipatory Systems*, edited by D. M. Dubois, AIP Conference Proceedings – 517, Amercian Institute of Physics, 2000, pp. 3-30.
21. P. E. Griffiths and R. D. Gray. "Darwinism and Developmental Systems", in: *Cycles of Contingency: Developmental Systems and Evolution*, edited by S. Oyama, P. E. Griffiths, and R. Gray, Cambridge: MIT Press, 2001, pp. 195-218.
22. K. N. Laland,., F. J. Odling-Smee and M. W. Feldman, "Niche construction, biological evolution, and cultural change", *Behavioural and Brain Sciences*, **23**, 131-175 (2000).
23. P. A. Corning, *Holistic Darwinism: Synergy, Cybernetics, and the Bioeconomics of Evolution*. University of Chicago Press, Chicago. 2005.
24. J. Avery. Information, Theory and Evolution, *World Scientific*, 2003.
25. Yuri M. Lotman, "O semiosfere", in *Sign Systems Studies (Trudy po znakovym sistemam)*, **17**, 5-23 (1984). (In Russian.).
26. J. E. Lovelock, *The Ages of Gaia. A Biography of Our Living Earth*, Oxford: Oxford University Press, 1988.
27. J. Brody, "Mutual bootstrapping" (A review of *Niche Construction: The Neglected Process in Evolution* by J. Odling-Smee, K. Laland, and M. Feldman. Princeton University Press, 2003), *The Human Nature Review*, **3**, 2003, pp. 484-487.

28. H. Williams, “Does global niche construction lead to environmental regulation?”, in: *Proceedings of Workshop on Modelling Environment Construction*, Tenth International Conference on the Synthesis and Simulation of Living Systems (ALIFE X), 2006, pp 153-154.
29. M. Conrad, “Bootstrapping on the adaptive landscape”, *Biosystems*, **11**, 167-182 (1979).
30. B. Dempster, “Sympoietic and autopoietic systems: A new distinction for self-organizing systems”, in: *Proceedings of the World Congress of the Systems Sciences and ISSS*, edited by J. K. Allen and J. Wilby, 2000, pp.1-30.
31. D. A. Perry, M. P. Amaranthus, J. G. Borchers, S. L. Borchers and R. E. Brainerd, “Bootstrapping in ecosystems”, *BioScience*, **39**(4), 231-237 (1989).
32. P. Aczel, *Non-well-founded Sets*, Stanford: CSLI, 1988.
33. A. Chemero, M. T. Turvey. “Complexity, Hypersets, and the Ecological Perspective on Perception – Action”, *Biological Theory: Integrating Development, Evolution, and Cognition*, **2(**1**)**, 23-36 (2007).
34. B. Goertzel, *From Complexity to Creativity: Computational Models of Evolutionary, Autopoietic and Cognitive Dynamics*, New York: Plenum Press, 1996.
35. A. Koestler. *The Ghost in the Machine*, London: Hutchinson, 1967.
36. K. Palmer, Vajra *Logic and Mathematical Meta-models for Meta-systems Engineering: on the Foundation of Holonomic Metasystems Theory and Engineering*, Copyright 2001 K. D. Palmer. All Rights reserved. Version 0.01; 11/20/01; v101a01.doc http://dialog.net:85/homepage/resume.html
37. K. Palmer, *Systems Engineering Research Pag*, http://holonomic.net
38. K. Palmer, *Introduction to Reflexive Autopoietic Dissipative Special Systems Theory: An approach to Emergent Meta-systems through Holonomics*, http://works.bepress.com/cgi/viewcontent.cgi?article=1003&context=kent_palmer
39. M. Wheeler, *Reconstructing the Cognitive World: The Next Step*, The MIT Press, 2005.
40. V. I. Kryukov, “An Attention Model Based on the Principle of Dominanta”, in *Neurocomputers and Attention I. Neurobiology, Synchronization and Chaos* edited by A. V. Holden and V. I. Kryukov, Manchester University Press, 1991, pp. 319-352.
41. V. Turchin, *The Phenomenon of Science. A cybernetic approach to human evolution*, New York: Columbia University Press, 1977.
42. F. Heylighen, Bootstrapping knowledge representations: from entailment meshes via semantic nets to learning webs, *Kybernetes*, **30**(5/6), 691-722 (2001).
43. M. Kiemen, “A triple loop model to ground higher-level cognition”, in: *Proceedings of the 18th European Meeting on Cybernetics and Systems Research*, **2**, 369-374 (2006).
44. S. Dehaene, M. Kerszberg, and J. P. Changeux, *Neurobiology*, **95**(24), 14529 -14534 (1998).
45. H. Olff, D. Alonso, M. P. Berg, B. K. Eriksson, M. Loreau, T. Piersma, and N. Rooney, “Parallel ecological networks in ecosystems”, *Philosophical Transactions of the Royal Society B: Biological Sciences*, **364(**1524), 1755-1779 (2009).