International Journal of Computing Anticipatory Systems, Edited by D. M. Dubois, CHAOS, Liège, Belgium, Volume 29, 2014, pp. 141-156. ISSN 1373-5411 ISBN 2-930396-18-0 (Best paper award).

Life Self-Design: Agential Anticipation in Central Nervous System

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Abstract. The aim of this study is an attempt to give new constructivist interpretation of well-known "dominant principle" of the outstanding Russian physiologist A. A. Ukhtomsky, which in a narrow sense, is a conceptual model of mechanism of motivated behavioral response of man or higher animals. Ukhtomsky's "Dominanta" is treated as developing situational material agency, expanding on the whole organism. The hypothesis is proposed here, that it is bootstrapping via cyclic processes of inward self-design and outward environmental design [13]. This design is based on strong anticipation. The process of Dominanta bootstrapping thus re-establish equilibrium inside the body system organization and, via sensor-motor coupling, equilibrium in the body-environment system in accordance with phenomenology of constructivism.
Keywords: agency, self-design, anticipation, dominant principle, functional system.

1.Introduction

Last time many studies are devoted to the analysis of some features and strategies of biological systems' self-design, which virtually is a mechanism of evolution of complexity and anticipatory behaviour. There are several strategies of self-design in neurophysiology. Particularly, *inverse design*, *backward determination and circular causation* are realized in the conceptual models of neurophysiology, which are based on so-called «Dominant principle» of outstanding Russian physiologist A. A. Ukhtomsky. The dominant principle states the existence in the central nervous system at every moment of only one active dominating center of excitation, associated with the most

actual, urgent current needs and desires. This focus of excitation play role of situational nervous center, agency for organization of physiological and behavioral response, directed on satisfaction of these needs. At the same time all other wishes and desires are suppressed. In the process of development and expansion Dominanta includes not only neuronal, but all processes in organism.

This principle is only partially realized in the form of "functional system" conception by P. K. Anokhin (see below, section 4) and in so called "dominant oscillatory architecture of sensorial information processing in brain" by V. I. Kryukov (section 5).

Self-design strategies working in ontogenesis or process of individual development and at the immunological response have common features. **Self-design here is a bootstrapping cyclical material-informational process, transforming the state of the whole nervous system and state of organism and environment.** In its turn, biological evolution is always associated not only with self-modification of genome but concurrently, with the bio-transformation of local milieu which can have backward influence on organism as a selective factor in Darwinian evolutionary mechanism (e.g. bioturbation and niche construction). At last, many features of biosphere are the result of circular hermeneutic process of biological species and environment co-evolution [13, 14].

According to hypothesis, proposed here, mentioned above features of self-design strategy are universal and can be revealed in mechanism of Dominanta bootstrapping.

The aim of this article is to demonstrate, that models of outstanding physiologists A. A. Uchtomsky and P. K. Anokhin well fit to concept of material agency bootstrapping according to universal self-design strategy, as described above. Moreover, on the opinion of the author, many aspects of anticipatory behavior of living system can be effectively described in these terms.

Far-fetched perpective of this line of investigations is to contribute to a new synthesis in framework of embodied, embedded, extended mind conception (EEEM) and to give some constructive proposals concerning modeling of cognitive, particularly, anticipatory behavior and evolution of biological systems in terms of self-design and anticipatory behavior.

2. Concepts of Agency and Design in Biology

"I characterise design as a conversation, usually held via a medium such a paper and pencil,with an other (either an "actual" other or oneself acting as an other) as the conversational partner".

Ranulf Glanville

Interest of leading specialists in natural science to the concepts of agency and design is growing [6, 7, 8, 9,] though, it is not new. Agency implicitly presents in the definition of anticipatory system by Robert Rosen [10]. Virtually, R. Rosen defined

agential type of anticipation which could be called weak anticipation [3]. Jesper Hoffmeyer, specialist in bio-semiotics and theoretical biology related the problem of the origin of life with the origin of autonomous agent [11]. Autonomous and autopoietic systems by H. Maturana and F.Varela could be called agencies. Concept of agency was extended and applied to artifacts in the form of "material agency" [1]. Martin Heidegger assigned an ontological statute to equipment and Bruno Latour [12] – to any material agency. Vladimir Vernadsky coined the term "bioinert matter" which plays as an important role in biogeochemical cycles as the "living matter" [13, 14].

Bio-artifacts and other environmental objects are elements of indirect interaction [13]. But, in this paper accent is made on active organizational agencies, responsible for cognitive, particularly anticipatory behavior of living organisms, living systems and "living systems extended", in framework of "extended life" hypotheses, or enactivism.

It is pertinent to note, that Russian outstanding physiologists such as I. M. Sechenov, I. P. Pavlov and A. A. Ukhtomsky were pioneers in search of these structures in central nervous system.

Particularly, A. A. Ukhtomsky formulated the so colled «Dominanta principle». According to this principle, the volition, associated with the sutisfying of the most urgent for organism's survival demands in concrete situation at any moment is associated with forming of dominant focus of cortical exitation, operating to exclude and inhibit all other concurrent functions, thus concentrating efforts on solving the most actual living problem. Our brain always chooses just one focus of excitation, which virtually, play role of situational nervous center of behaviour control. All these centers of excitation are labile and switching between them is associated with change of attention.

There is a tendency to extend concept of design, traditionally associated with the conscious, goal-oriented human creative activity (action, decision making) for biology and artificial intelligence. Indeed, biological organisms demonstrate wide spectrum of adaptive goal-oriented behavior. In contrast to inert matter, living organisms and living systems in general have a genuine faculty to reconfigure its own structure and structure of local environment in adaptive, goal-oriented manner. For example, they have innate or acquired via learning in the course of life mechanisms for construction of situational neural, sensory-motor, and other dynamic structures, transient organizations which mobilize organism's resources for achieving of the most actual in concrete situation behavioral or physiological goals by inhibition or submission all other functions, associated with other goals, virtually, at the expense of these functions. This mechanism can be both conscious and unconscious. Organisms use their body as a universal constructor and in this sense they are self-designers not only when they demonstrate adaptive behavior or physiological reactions, but also in the process of individual development and evolution. But, who or at least what is the designer in all these phenomena? Can it be individual or distributed, social agent? When we apply conception, conventionally used in human practice to biological objects, we try to avoid subjective anthropocentric view of the problem. It is difficult to imagine designer as a self when we think about worm, plant or bacteria. Nevertheless, the candidate for constructors or at least, the initiators of situational structures can well be some non-

anthropocentric agencies [1]. These agencies or virtual structures, which participate in organization of physiological reactions, individual development, learning and evolution, are really mechanisms of anticipatory behavior.

Design and anticipation are tightly coupled concepts and constitute a special kind of relation [2]. Anticipation plays a crucial role during any action, particularly in agents, operating in open, complex and dynamic environments. This paper is focused on the role of anticipation from a design perspective. Living organisms are designers of local environment and self-designers concerning their own structures. Indeed, anticipation is associated not only with the faculty of looking into future but also refers to an action that is taken in preparation for future event. Living systems are classified as anticipatory ones according to any definition. As far as they can use model-based prediction of future state, they can be characterized as weakly anticipatory systems. At the same time, they can be strongly anticipatory systems in which future state is computed in self-referential manner when goal is emergent and constructed en-route [3, 4]. On the basis of predicted future states, complex self-organized biological systems should have concrete mechanisms, structures for realization of anticipatory behavior. These structures, or agencies are being designed by organism both in its internal milieu (via neural, immune, humoral or metabolic systems), as well as in an external local environment (via bioturbation, niche construction, stigmergy, or bio-semiotic processes).

3. The Principle of "Dominanta" by A. A. Ukhtomsky

"What is the difference between an animal physiological mechanism and a technical mechanism? First, it is generated during the course of the reaction. Second, once chosen, a behavior in technical mechanism is secured once and forever by a construction, whereas as many different processes are realized successfully on the same construction as in a reflex apparatus as the number of degrees of freedom. Each of the successfully realized processes is achieved due to active inhibition of all the other processes except one"

A.A. Ukhtomsky

Russian outstanding physiologist A. A. Ukhtomsky first revealed direct influence of motivation on dominating type of behavior and mechanism of attention. The motivation (i.e. aspiration to reach a certain purpose) is an important property of "intelligent" animal behavior. It is included as significant participant in *functional system* of higher nervous activity by P. K. Anokhin (see below). The motivation is closely correlated with phenomenon of *"Dominanta"* by A. A. Ukhtomsky.

The "principle of *Dominanta*" [16] is a good illustration of emerging and developing of situational embodied agency which at first moment appears as a focus of excitation in Central Nervous System and then transcends nervous system and expands on the whole organism. It plays role of integrator and coordinator of organism's goal-directed behavior, the goal itself being formed in the course of *Dominanta* development.

On successful completion of physiological act and reach of goal *Dominanta* self-annihilates. The principle of *Dominanta* in a narrow sense states the existence in the central nervous system (CNS) at any point of time of only one active, dominating focus of excitation that attracts to itself other subdominant excitations impinging on the nervous system at the same time, and that renders inhibitory influence in the activity of all other centers. This constellation of excitations produces the adaptive behavioral reaction directed on satisfaction of current, the most urgent requirements of organism in this moment.

The center of excitation in the brain (the dominant focus) suppresses all other desires and needs, ignore any resistance. The main principle of the dominant is a mechanism of brain which chooses just one focus of excitation. At this time all other needs and wishes are not taken into account by the brain. They get reoriented under the dominant submission. This principle is very useful because in this way we are able to meet the main need and we can do it well and quickly.

A. A. Ukhtomsky came to this idea when he demonstrated for students an experiment on electrical stimulation of the motor cortex of a dog. To his dismay, stimulation produced no movement, even when he increased the strength of the current. Suddenly the dog defecated, and immediately following this, cortical stimulation once again produced a motor response.

On its appearance the *Dominanta* is an integral system which from its first moment, say, generates a central program of bootstrapping (a kind of algorithm, or set of instructions or directions). The latter includes not only the sequence of motor acts, but their intermediate final results. P. K. Anokhin (see next section) in his model of functional system made accent on this aspect of *Dominanta*.

In his monograph, devoted to analysis of contribution of A. A. Ukhtomsky to integral science of man [17] L.V. Sokolova tried to reconstruct scheme, illustrating process of *Dominanta* development and action on the level of the whole organism as factor, organizing goal-oriented behavioral act [Fig. 1]. The detail commentary in English to this scheme will be given in a collective monograph “Advances in Russian and International Neurotechnology”, edited by Chris Forsythe, Michail V. Zotov, Gabriel A. Radvansky and Larisa Tsvetkova. The monograph will be published in CRC Press next year.

4. Anokhin’s Theory of Functional Systems

The disciple of Ivan Pavlov and one of followers of A. A. Ukhtomsky, Piotr Kuzmich Anokhin developed conception of functional system [18, 19]. Functional system was proposed in 1930s as “a complex of neural elements and corresponding executive organs that are coupled in performing defined and specific functions of an organism. Examples of such functions include locomotion, swimming, swallowing, etc. Various anatomical systems may participate and cooperate in a functional system on the basis of their synchronous activation during performance of diverse functions of an organism”.

Contrary to reflexes, the endpoints of functional systems are not actions themselves but adaptive results of these actions. This conceptual shift requires understanding of

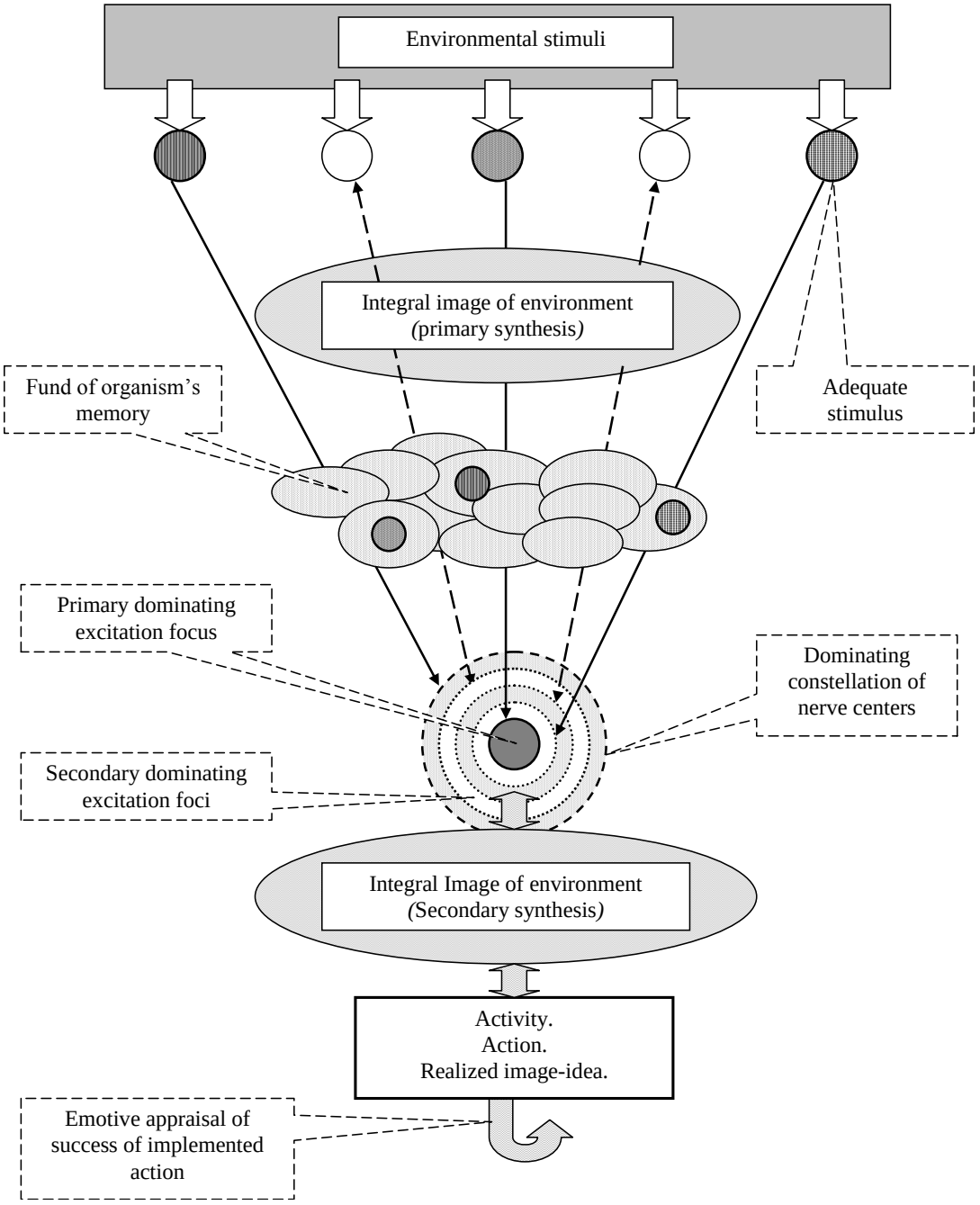

Figure 1: Ukhtomsky's "Dominanta" as a factor of organization of goal-directed behavior (rewritten with the permission of the author, Sokolova L.V. (2010) [17]).

biological mechanism for matching results of actions to adaptive requiremens of an organism, which are stored as anticipatory models in the nervous system.

A biological feedback principle was introduced in the scheme of the functional system in 1935 as a backward afferentation flowing through different sensory channels to a central nervous system after each action. **An anticipatory neural template of a required result placed into memory before each adaptive action was called an acceptor of the result of action.**

The term *acceptor* carries two meanings derived from its Greek root: (1) acceptor as a receiver of the action's feedback, and (2) acceptor as a neural template of the goal to be compared with feedback and, in the case of positive match between the model and feedback, followed by the action's acceptance.

In contrast to reflexes, which are based on linear spread of information from receptors to executive organs through the central nervous system, functional systems are self-organizing non-linear systems composed of synchronized distributed elements. The main experimental issues of research on functional systems amounted to understanding how this self-organization is achieved and how information about the goal, plans, actions and results is represented and processed in such systems. These studies led to creation of the conceptual scheme of stages of adaptive behavioral acts shown in Fig. 1.

The main stages of the functional system operation are (see Fig.2):

1) Afferent synthesis;
2) Decision making;
3) Generation of the acceptor of the action result;
4) Generation of the action program (efferent synthesis);
5) Performance of an action;
6) Attainment of the result;
7) Backward afferentation (feedback) to the central nervous system about parameters of the result;
8) Comparison of the result with its model generated in the acceptor of the action result.

Operation of the functional system includes: 1) preparation for decision making (afferent synthesis), 2) decision making (selection of an action), 3) prognosis of the action result (generation of acceptor of action result), 4) backward afferentation (comparison between the result of action and the prognosis). Operation of the functional system is described below.

Motivation is the important concept of functional system. The role of motivation is forming of a goal and providing of goal-directed forms of behavior. Motivation can be seen as an active driving force which stimulate finding of such a decision, which is adequate to needs of animal in current situation as in the concept of *Dominanta* coined by A. A. Ukhtomsky.

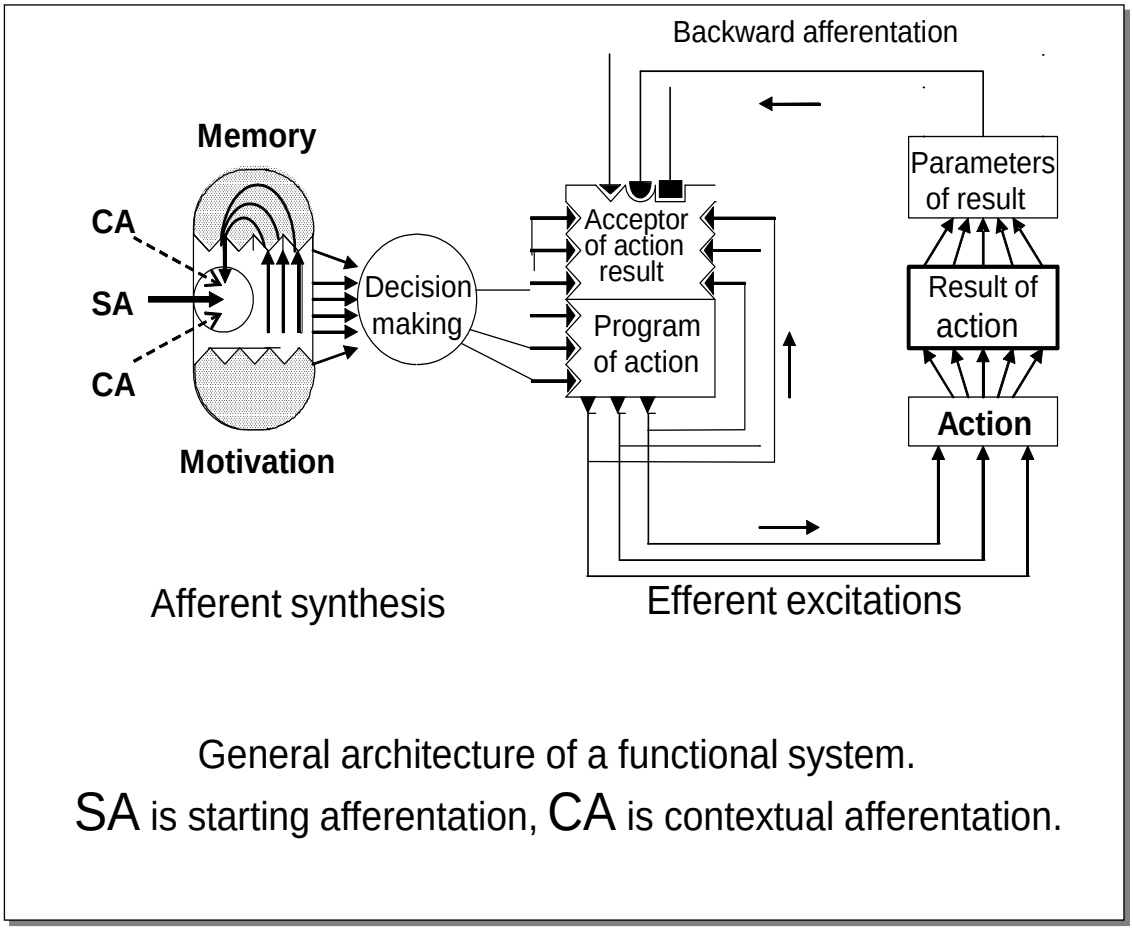

Figure 2: Architecture of Functional System in Central Nervous System by P. K. Anokhin (redrawn from the article of Red'ko V.G. et al., [20] with the permission of the authors).

Of course, scheme (Fig. 2) cannot reflect all aspects of functional system. Functional systems are dynamic, self-organizing and self-regulatory central-peripheral organizations the activity of which is aimed at achieving adaptive results useful for the system and the organism as a whole. A multitude of useful adaptive results that form different functional systems are present on metabolic, homeostatic and behavioral levels defining optimal for vital activity metabolism and adaptation of the organism to the environment.

There are two principally important features that make the Anokhin's theory of functional systems essentially different from the general theory of systems developed by L. von Bertalanffy and his disciples. They are the following:

1. Useful adaptive results, which are system-forming factors in functional systems and play a crucial role in the process of multi-component association into functional systems providing various manifestations of the organism's adaptive activity.
2. Dynamic, operational architectonics with compulsory reverse afferentation signaling into the central nervous system from the result of its activity.

Functional systems of any organizational level have a similar structural design and include the following common and shared by different systems peripheral and central principal mechanisms: 1. Useful adaptive result as a main functional system component; 2. The result's receptors; 3. Reverse afferentation coming from the result's receptors into the central units of the functional system; 4. Center representing nervous elements of different level selectively associated by the functional system into special system mechanisms; 5. Executive somatic, autonomic, immunologic and endocrine components including organized goal-directed behavior. Since in principle different functional systems of the body are uniformly designed, they are rightly considered to be isomorphic. In functional systems of behavioral and psychic levels of organization, the external link of self-regulation is dynamic environment-oriented behavioral activity of living beings aimed at the environment adaptation in accordance with body needs and at the achievement of behavioral results able to satisfy corresponding body needs and eventually to secure its survival. Therefore, the environment naturally participates in the activity of many functional systems of the organism. Only through body interaction with the environment these functional system acquire the results beneficial for the organism. In a functional system, every shift of result as well as its optimal for the metabolism level is continuously perceived by corresponding receptors. Signals (“reverse afferentation” according to P.K. Anokhin) born in receptors come to the corresponding centers and selectively involve various level elements into the given functional system in order to give rise to its executive activity and thus restore the result needed for metabolism. Reverse afferentation is the background of self-regulatory processes in any functional system. Excitation of nervous centers occurs in a functional system of behavioral and psychic levels of organization on the basis of reverse afferentation presented by nervous impulses and humoral effects from the result.

The concept "reverse afferentation" was introduced into physiology by P.K. Anokhin 12 years before N. Winner, who as is well known has formulated the notion “feedback”.

Through formulating the notion of reverse afferentation P.K.Anokhin established a recognized priority in the cybernetics of living.

Independent of its structural complexity, any functional system has similar central architectonics. Central architectonics of the functional systems includes the following principal stages consecutively replacing each other: afferent synthesis, decision making, acceptor of action's result, efferent synthesis, and, finally, assessment of the achieved result.

The structure of behavioral level in functional systems is similar. The initial stage in the structure of behavioral level of a functional system is afferent synthesis. At this

stage, the central nervous system experiences the synthesis of excitations caused by inner metabolic need, by environmental and trigger afferentation, with constant utilization of genetic and individually acquired memory mechanisms. The afferent synthesis stage terminates with a decision making stage, which physiologically restricts the functional system activity freedom rate and selects the only effector action line able to satisfy the leading organism's requirement formed at the afferent synthesis stage.

The next stage in the dynamics of consecutive central architectonics development taking place simultaneously with effector action formation is the stage of predicting the required result of the functional system activity, i.e. the acceptor of action's result. At this stage of the functional system central organization, the programming of the principal parameters of the required result and their constant assessment based on reverse afferentation of the achieved result parameters takes place. When a significant result satisfying the initial organism need is achieved the activity of the functional system decreases. And vice versa, if the achieved result parameters do not correspond to the parameters of the acceptor of action's result, there occurs a mismatch, i.e. orientating searching reaction; afferent synthesis is restructured, a new decision is made, and the functional system follows in a new direction required for the initial need satisfaction. Effector action is preceded by the efferent synthesis stage, when an executive act is center-formed as a certain central excitation complex and is not accomplished peripherally as particular actions.

All stages of achievement of organism-beneficial results and their various states are continuously assessed through reverse afferentation. Reverse afferentation arises when respective receptors are stimulated by result parameters and via respective afferent nerves and humoral factors arrives in structures forming the acceptor of action's result. If reverse afferentation bears no valuable information concerning the optimal result level, the nervous cells of the acceptor of action's result are excited, a new afferent synthesis takes place and a new action occurs.

The number of functional systems reflecting various aspects of the whole organism vital activity is extremely high. The activity of some functional systems affects different characteristics of the organism's internal milieu - homeostasis, and the processes of homeokinesis leading to it. Other functional systems through their activity modify living beings' behavior, their interaction with the environmental and social factors to pursue different forms of social activity, for instance, to start a family, to organize household and place of work. Finally the need arises to build the society in the best possible way, and so on. Each functional system presents a dynamic self-regulatory organization. The central point of functional systems found at different organizational levels is an organism-beneficial adaptive result. Any deviation of the result from the level ensuring normal life of the body are immediately perceived by receptor mechanisms, and by way of nervous and humoral reverse afferentation special central mechanisms are selectively engaged. By these executive means, including behavior, the latter mechanisms once again bring the useful adaptive result to the level necessary for normal metabolism. All these processes go on continuously while the functional system center is permanently informed of the successful achievement of the useful adaptive result, i.e. in compliance with the self-regulatory principle.

Due to Anokhin, the final result of the action from the very beginning becomes a constituent part of the generated algorithm of functional system development. The goal of behavior, emerging in the genesis of each evolving functional system simultaneously implying its final result is its purpose. It is serious simplification of the idea of Dominanta. The theory of functional system is mechanism of anticipatory adaptive behavior, in which final result is the constituent part of decision making process. But, as earlier A. A. Uchtomsky and later P. K. Anokhin noticed, all elements of Dominanta or Functional system emerge and are working concurrently.

5. Attempts to Model Goal-Oriented Behavior on the Principles of the Conceptions of Functional System and Uktomsky's Dominanta

Group of authors (Vladimir Red'ko et al., 2007) [20] attempted to design an animat control system (the Animat Brain) on the basis of the P. K. Anokhin's theory of functional systems. The Animat Brain is aimed at controlling adaptive behavior of an animat that has several natural needs (energy replenishment, safety, reproduction). The animat control system consists of a set of hierarchically linked functional systems and enables predictive and purposeful behavior.

In the first version of the Animat Brain author tried to use the reinforcement learning approach, namely they used adaptive critic design (ACD), consisting of two neural networks based blocks: model and critic. Both neural networks are differentiable feed-forward multilayer perceptrons or recurrent neural networks. Adaptive critic serves to select one from several actions. For example, for movement control the actions can be move forward, turn left, turn right. The animat in any moment should select one of these actions. The goal of adaptive critic is to maximize stochastically utility function.

However, simulation of ACD agents demonstrates that correct ACD operation can be evolutionary unstable: evolution reorganizes ACD operation in some sophisticated manner.

In the next, advanced version authors developed more biologically plausible Animat Brain architecture, which is based on the functional system that consists of the model NNs and the controller NNs. The controller NNs are intended to form chains of actions and the model NNs are intended to predict future events. In the case of unexpected events, considerable learning takes place and animat behavior is reorganized. Author try to find conditions in which predictions of future events (formed by model NNs) and generations of chains actions (formed by controller NNs) are consistent with each other [20].

V. I. Kryukov [15] returned to idea of Dominanta by A. A. Ukhtomsky and realized it in more full measure, than P. K. Anokhin. He put forward a star-like system consisting of group of N originally independent peripheral cortical oscillators and one central oscillator (CO) which has only 2N connections with peripheral counterparts (SO).

The central oscillator acts as a global pacemaker, or an "orchestra conductor".Attention is switched by from one group of oscillators to another in succession by changing the frequency of central oscillator. Thus we have parallel-serial type of processing.

This architecture differ from well-known connectionist one ("Global Workspace", [21]). Besides, information is stored not in synaptic links, but in space-frequency *isolabile* configurations of oscillators with similar natural frequencies and with their learning being centrally controlled.

Global information processing in the brain is working by the analogy with radar with central oscillator as "neurolocator". CO sends a series of theta-modulated pulses to neocortex, end then receives "echo" to determine their phase relative to central oscillator.

This architecture accounts for parallel, concurrent character of processes in brain and reminds communicative scheme by Gordon Pask (The Theory of Conversations).

6. Ukhtomsky's "Dominanta" Revival

"…after evolution discovered how to make physical bodies that grow themselves, it discovered how to make virtual machines that grow themselves".

A. Sloman and J. Chappel

A. A. Ukhtomsky was not only outstanding physiologist, but also great thinker and philosopher. He saw the universal sense of his principle far beyond neurophysiology and came to philosophical generalizations. Resent deeper analysis of his works made clear, that some ideas, developed in the conception of *Dominanta* were re-opened and by authors of enactivism and neurophenomenology [23, 24].

Dominant ensemble of neurons is really a temporal control agency in the body. But, according to A. A. Ukhtomsky, in the process of development, *Dominanta* transcends the nervous system and even body of organism and control aspects of environment.

The similar strategy of self-design is realized in ontogenesis, or individual development. It is really a bootstrapping process of embodiment with construction of cascade of anticipated contexts, mediums which then perform canalization of morphogenesis via *downward determination.*

Immunological response in the interpretation of clonal selection model is the example of *backward bootstrapping* process. Biological evolution is always accompanied by the bio-transformation of local milieu which can have backward influence on organism as a selective factor in Darwinian evolutionary mechanism (e.g. bioturbation and niche construction). At last, many features of biosphere are the result of circular hermeneutic process of biological species and environment co-evolution. So, an anticipation and design are closely related concepts, and that relationship has been in the focus of interest of a number of specialists

Recently, M. V. Butz [5] stated, that brain is an anticipatory device that (1) continuously forms expectations about the future and (2) uses these expectations for generation of effective anticipatory behavior. He proposed, that "brain development is controlled by an inherent *anticipatory drive*, which biases learning towards the formation of forward predictive structures and inverse goal-oriented control structures" ([5], p.1-2). He put forward a hypothesis that this drive is responsible for forming of conscious self. But, this is only one side of the coin. Anticipatory behavior is concurrently related with the goal-directed or non-goal-directed transformation of local environment. Further development in this direction can help to come to a new synthesis of all aspects of design processes, leading to construction of brain – body – environment anticipatory agencies, responsible for anticipatory behavior of biological organisms and possibly, ecological systems.

It should be noted that ontogenesis, evolution or immune reaction demonstrate such unusual faculties, as self-modification. Moreover, they fall into class of "bootstrapping systems" [13], which co-evolve with their environments in special circular "dance" (Fig 3). According to hypothesis, put forward in this work, Ukhtomsky's Dominanta and functional systems are also self-modifying [22] and bootstrapping systems. Bootstrapping of these virtual material agents follow the same strategy: self-modification, – modification of environment, – selection of the system by environment and so on. At first moment, *Dominanta* is only focus of excitation in central nervous system. But in the course of development it subordinates the whole nervous system and then modifies the state of the whole organism including humoral and other systems of organism. The system constantly reconstructs itself using elements of incessantly expanding environment and at the same time, transforms that environment. It is emergent material–information process. So, *Dominanta* is a self-constructing, self-modifying system, bootstrapping inside organism. The environment here is really the whole hierarchy (or holarchy?) of environments with distributed memories of all sorts [see Fig.1], which *Dominanta* uses when it goes through organism as a soliton, assimilating processes and subordinating them ia result, everything is aimed at performance of physiological and behavioral act.

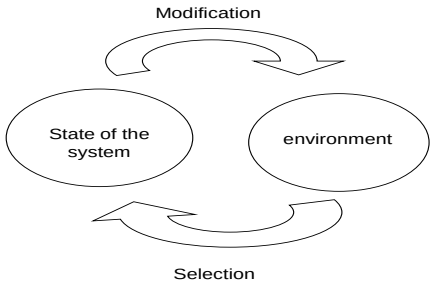

Figure 3: Strategy of material agency bootstrapping

Do we have nowadays an adequate formal instrument for description of these material–informational processes? Maybe formal technologies [25], new branch of the theory of algorithms will become a perspective instrument for description and modeling of these systems. Formal technologies operate with wide spectrum of objects, not necessary with numbers. These objects can be of any nature, e.g. geometrical and physical bodies. Nevertheless, we can try to make simulations, accounting for not only neural but other "material" processes in organism.

6. Conclusion

Agential form of anticipatory behavior is characteristic to all forms of living organisms. Agency can be seen as an emergent, situational dynamic structure, organizational center of embodied and embedded mode of living organism existence. Evolution of agential form of anticipatory behavior of living organisms is a very interesting new perspective theme for investigations.

Concepts of agency and design form a complementary couple, which is conducive for analysis of adaptive and anticipatory behavior of living organisms.

As was marked above, in the process of *Dominanta* emerging, embodiment, bootstrapping and die down, perception, cognition and action form a whole system with interpenetration. This integral aspect of sensory-motor system was recently re-opened [26]. In this work, Andy Clark speculates about pervasive notion of neural code or codes. He concludes that the vision of the human brain as an organ of pure reason is gone. Instead, we encounter brain as a locus of action-oriented, activity-exploiting problem-solving techniques, and as a potent generator and exploiter of cognition-enhancing "wideware". Aspects of environment in its turn emerge as a fundamental component of natural problem solving behavior.

Thanks to mechanism of *Dominanta* biological organism became really self-modified system.

If Anokhin's model of functional system fit naturally into classical cybernetic scheme, Ukhtomsky's *Dominanta* adequate interpretation is possible only in context of second-order cybernetics, neurophenomenology, enactivism and other contemporary conceptions. Proposed general mechanism of *Dominanta* bootstrapping via cycles of self-modification – modification of environment still waits for its concretization in formal models.

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