On Modeling the Role of Negative Emotions and the Effect of Panic in an Artificial Cognitive System

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***Abstract*— We continue a series of works on modeling especially the human aspects of cognitive process, such as intuition, the influence of emotions, the role of personality, etc. The Natural Constructive Cognitive Architecture proposed and analyzed in our previous works has an important design feature: the entire system consists of two connected subsystems conventionally corresponding to the cerebral hemispheres of human brain. One of them is responsible for the processing of well-known information, the other is aimed at learning new information and creative work. This paper is focused on analyzing the extreme mode of thinking process, namely, the effect of panic in creative work ("throes of creativity"). It is shown that the regime of panic in an artificial cognitive system could be imitated by chaotic fluctuations in the amplitude of self-excitation around an abnormally high level. A sharp drop in the self-excitation level below the normal value (ensuring normal system's functioning) leads to a decrease in efficiency (an analogue to the depression).**

Keywords-emotions; creativity; noise; chaotic oscillations; extreme conditions.

I. Introduction

Modeling the human cognitive process still represents a challenge in spite of considerable efforts undertaken in this field [1] – [3]. The influence of emotions to the logical thinking attracts especial attention [4] – [6], but the problem has no ultimate solution yet. In particular, this concerns the features of human thinking in difficult (extreme) situations [7], disease [8][9], stress [10], etc.

In our previous papers [11] – [15], we have proposed and elaborated the so called Natural Constructive Cognitive Architecture (NCCA). This model has an important design feature: the entire system consists of two connected subsystems (*hemi*-systems), conventionally corresponding to the cerebral hemispheres, the right (RH) and left hemi-systems (LH), respectively. One of them (LH) is responsible for the processing of well-known information (recognition, prediction, etc.), the other one (RH) is aimed at the perception of new information, learning, and creative work.

The idea that any developing system should consist of two subsystems, one for generating an information (with the obligatory participation of a random element – noise), the other one for conservation of information (noise free) had been put forward in the works of Haken [16] and Chernavskii from the theoretical physics viewpoints [17]. Independently, similar idea appeared in the works of neuro-psychologist-clinician Goldberg [3] and was supported by clinical data (tests, fMRI study, etc.). He had argued that the generating subsystem corresponds to the Right Hemisphere (RH) of human brain, while the conservation subsystem could be associated with the Left Hemisphere (LH).

Within NCCA, this specialization is ensured by the presence of random element (noise) in RH (random self-excitation of neurons). Each hemi-system represents a complex multi-level hierarchical structure of various neural processors [18] – [20], with connections between neurons are to be trained according to different rules in RH and LH. Emotions are treated as a product of interaction between cortical and subcortical structures [21][22].

In this paper, NCCA is used to analyze the extreme mode of the cognitive process – the effect of panic. We consider the panic caused not by certain external (threatening) factors, but by the need to solve urgently any complex problem (the so-called "*throes of creativity"*).

The paper is organized as follows. The problems of creativity are considered in Section II. In Section III, the main peculiar features of NCCA and our hypothesis on possible panic representation are discussed. Conclusions and discussion of further perspectives are presented in Section IV.

II. Problems of Creative Work

The creativity is treated as the ability of a person to find non-standard and nontrivial new decisions, to generate and perceive fundamentally new ideas and concepts [23][24]. Up to some degree, this ability is inherent in any person who is placed in new and, especially, extreme conditions. However, very rarely a new concept invented by a person becomes socially significant and considered as a *chef-d'oeuvre,* while the person is treated as a genius. Generally speaking [24], the creativity requires:

- ability to extract key issues and ask important questions;
- striving for novelty and the ability to find new solutions even for old problems;
- ability to correlate old knowledge with new problems;
- flexibility of thinking, i.e., the ability to abandon dogmas if new information contradicts them;
- perseverance and focus on solving the problem;
- "free wandering thoughts".

But all this is not a *recipe* for creating a *chef-d'oeuvre* — such recipe does not exist at all, which is really an *enigma* [15].

From a neurophysiological viewpoint [25][26], it is believed that RH and the *prefrontal cortex* are responsible for the processing the new information and creativity. Actually, this formula is not entirely correct. Creativity is a complex

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process requiring participation of many brain structures in RH and LH. Thus, the flexibility of thinking and the *free wandering thoughts* are associated with *image* thinking, while *focus* requires activation of both frontal lobes. The comparison of old and new knowledge occurs in the dialogue between RH and LH, etc. [24].

Under extreme conditions, the extreme modes of the brain functioning (like *stress, hyperactivity*, etc.) could be switched on, which is accompanied by emotional instability [10]. In this case, the emotional excitation activates the latent ("sleeping") neurons (self-excitation), but there is a huge expenditure of energy. Naturally, such regime cannot last long. It may end in success, i.e., a decision satisfying the person and causing a surge of positive emotions. If the solution had not been found, the *depression* (loss of strength) occurs that could be associated with an energy overrun.

An extreme case of specific regimes is called a *panic*. Usually, panic is understood as a strong stress response to unexpected and frightening external phenomena. Moreover, a person's behavior in a state of panic is individual, unpredictable and usually *chaotic*, from febrile activity to falling into a stupor [7][8][23].

However, we consider not the reaction to a threat to life, but to the need to solve urgently certain cognitive (intellectual) problem. Here, the intensive (up to the stress regime) search for a solution could lead to increased stress up to the regime of *intellectual panic*, which is called also "*throes of creativity*". This regime is characterized by the same (may be not so pronounced) manifestations: chaotic emotional jumps from euphoria (when the solution seems to be found) to disappointment (if it appears to be incorrect), and again, from over-mobilization to complete decline and despair (*depression*).

Thus, negative emotions (anxiety, worrying) and the panic in particular can play both negative (destructive) and positive (constructive) role, if expressed in over-mobilization and does not result in deep depression.

III. MAIN FEATURES OF NCCA

The model NCCA has been elaborated in [11][12][13]. It is based on the dynamical theory of information [16][17][30], neuroscience [21][22], and neurocomputing [18] – [20]. Let us recall briefly its main features.

A. *Mathematics and schematic representation of NCCA*

The system is combined by two coupled hemi-subsystems, RH and LH, by analogy to the cerebral hemispheres of human brain. They represent complex multilevel block-hierarchical combination of neural processors of the Hopfield [16] type (***H***) and Grossberg [17] type (***G***), referring to description of neocortex. These equations could be written in the form:

$$\frac{dH_i^0(t)}{dt} = \frac{1}{\tau_i^H}[\Im_H\{H, \beta_i(G^R{}_{\{i\}})\} + \sum_{i\neq j}^{n} \Omega_{ij}^{Hebb} H_j^0 + $$
$$+\sum_k \Psi_{ik}\, G_k{}^{R,1} - \Lambda(t)\cdot H_i^{typ}] + \frac{1}{\tau^Z} Z(t)\cdot\xi_i(t), \qquad (1)$$

$$\frac{dH_i^{typ}(t)}{dt} = \frac{1}{\tau_i^H}[\Im_H\{H, \beta_i(G^L{}_{\{i\}})\} + $$
$$+\sum_{i\neq j}^{n} \Omega_{ij}^{Hopf}\cdot H_j^{typ} + \sum_k \Psi_{ik}\cdot G_k{}^{L,1} + \Lambda(t)\cdot H_i^0], \qquad (2)$$

where, H^0_i (*raw* images) and H^{typ}_i (*typical* images) variables (bistable elements) refer to Hopfield-type processors [18] for RH and LH, respectively. These processors correspond to the distributed memory (*images*), where each object is represented by certain chain of excited neurons, Ω_{ij} refer to connections between neurons within the processor; the functional $\Im_H$ describes the internal dynamics. The variable *Z(t)* in RH represents amplitude of the random self-excitation, with $0<\xi(t)<1$ being random function, and τ^Z being characteristic time of *Z(t)* variations.

$$\frac{dG_k^{R,\sigma}}{dt} = \frac{1}{\tau_G}[\Im_G\{G_k^R, \alpha^\sigma{}_k(\{\Psi_{ik}^{R,(\sigma-1)}\}, G_k^{R,(\sigma+\nu)})\} + $$
$$+\hat{\Upsilon}\{G_k^{R,\sigma}, G_l^{R,(\sigma+\nu)}\} - \Lambda(t)\cdot G_k^{L,\sigma}] + \frac{1}{\tau^Z} Z(t)\cdot\xi(t), \qquad (3)$$

$$\frac{dG_k^{L,\sigma}}{dt} = \frac{1}{\tau_G}[\Im_G\{G_k^L, \alpha^\sigma{}_k(\{\Psi_{ik}^{L,(\sigma-1)}\}, G_k^{L,(\sigma+\nu)})\} + $$
$$+\hat{\Upsilon}\{G_k^{L,\sigma}, G_l^{L,(\sigma+\nu)}\} + \Lambda(t)\cdot G_k^{R,\sigma}]. \qquad (4)$$

Here, $G^{R,\sigma}_k$ and $G^{L,\sigma}_k$ represents the *symbols* [19] in RH and LH, respectively. They are also bistable elements with internal dynamics described by the functional $\Im_G$; Ψ_{ik} correspond to the connections between image neurons and their symbol; the functional Υ describes interactions between symbols at various levels, that results in creating the *symbolic images* at the current level and their symbols at the next level (for details see [13]). The marker σ specifies the number of the symbol-processor level.

The hemi-systems RH and LH have different functional specialization. RH plays the main role in learning of *new* information and creativity, while LH is responsible for processing the well-known information. This specialization is secured by the presence of random factor (*noise*) in RH and *different* training rules for all the connections, i.e., Hebbian rule [29] for RH and Hopfield one [18] for LH, e.g.:

$$\frac{d\Omega_{ij}^{Hebb}(t)}{dt} = \frac{\Omega_0}{4\tau^\Omega}\cdot[H_i(t)+1]\cdot\left[H_j(t)+1\right], \qquad (5)$$

that corresponds to gradual connection amplification with time in RH (the *choice*), and

$$\frac{d\Omega_{ij}^{Hopf}(t)}{dt} = -\frac{\Omega_0}{2\tau^\Omega}\cdot\left[1 - H_i(t)\cdot H_j(t)\right], \qquad (6)$$

that corresponds to the *selection* of relevant connections ("redundant cut-off") in LH**;** Ω_0 being the characteristic (maximum, or "black") value of the connection. Due to this difference, LH stores only well-trained ("black") connections, while RH stores as well weak (or "grey") ones.

Finally, *Λ(t)* secures the interaction ("dialog") between hemi-systems so as $\Lambda = +\Lambda_0$ corresponds to RH→LH transfer of activity, while $\Lambda = -\Lambda_0$ corresponds to LH→RH.

The schematic representation of NCCA is shown in Figure 1.

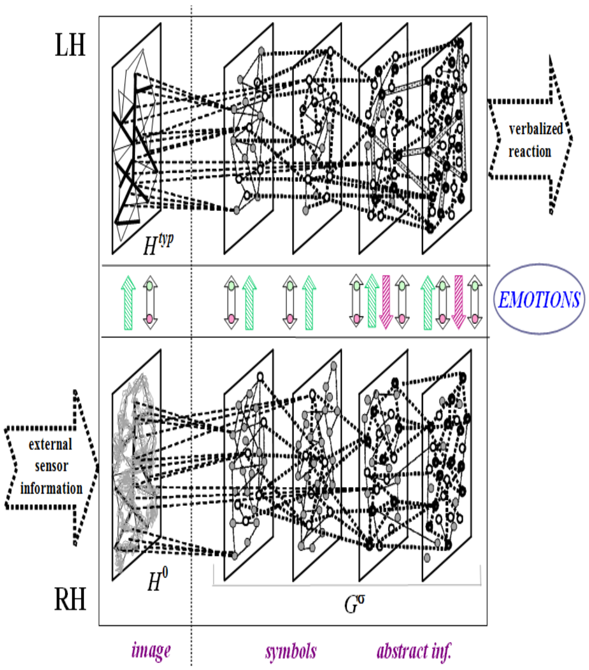

Figure 1. Schematic representation of NCCA.

The system evolves by self-development (in Figure 1 — from the left to the right). The ground (zero) level is represented by two ***H***-type processors (distributed memory) receiving the external information in the form of "raw" images (certain chains of excited neurons). Let us stress that the image plate $\boldsymbol{H^0}$ (so called "*fuzzy set*") in RH does play key role in intuition and actions under the extreme conditions. Actually, it could be treated as an analogue to the human *sub-consciousness* filled with personal subjective associations, thus presenting the source for nontrivial solutions.

All other levels σ = 1…*N* are presented by ***G***-type processors carrying out the *symbolic* information, with each symbol concentrates (being a convolution) all the information of its image [11].

The high-level symbols correspond to *abstract concepts*, which are not based on any raw image of real object (such as "*science*", "*problem*", etc.). However, they do control all the "parent" symbols at lower levels and thus could control the activity of the whole system. According to neuro-physiological studies, these very functions are character for the *frontal lobes* of human brain [8][9][24][25].

B. *Imitation of the extreme mode (panic)*

Note that the system of equations (1) – (4) is not complete in math sense, since the variables *Λ(t)* and *Z(t)* are not specified as yet. In [12][13], we argued that they are tightly connected with emotions. The last are considered as a product of interaction between cortical and subcortical structures [21][22], which influence mainly the random factor in RH. Let us recall briefly the math background of this concept:

$$\frac{dZ(t)}{dt} = \frac{1}{\tau^Z}\left[a_{Z\mu}\cdot\mu + a_{ZZ}\cdot Z + F_Z(\mu, Z) + \Theta(Z, H, G_k^\sigma)\right], \qquad (7)$$

$$\frac{d\mu}{dt} = \frac{1}{\tau^\mu}\left[a_{\mu\mu}\cdot\mu + a_{\mu Z}\cdot(Z - Z_0) + F_\mu(\mu, Z)\right], \qquad (8)$$

$$\Lambda(t) = -\Lambda_0 \cdot th\left(\gamma\cdot\tau^Z\cdot\frac{dZ}{dt}\right). \qquad (9)$$

Here, *Z(t)* is the amplitude of random (stochastic) component (*noise*) presented in RH only. The functional $\Theta\{Z, H_i, G_k^\sigma\}$ refers to the influence of variables H_i and G^σ_i (associated with the neocortex structures). The value Z_0 represents "normal" value of *Z(t)* necessary for regular system functioning, τ^Z corresponds to characteristic time of *Z(t)* variation.

The variable *μ(t)* in (7), (8) corresponds to purely "emotional" component produced by subcortical structures; it represents the effective composition of neurotransmitters (the difference between stimulants and inhibitors); τ^μ being the characteristic time for μ(t) variation.

The variable *Λ(t)* that is stitching together the equations (1)—(4), refers to the cross-hemi-system connections (like *corpus collosum* in brain), which provide the collaboration of two hemi-systems. The parameters τ^Z and γ control the pattern of *Λ(t)* variation.

In [14][15], it was shown that typical pattern of *Z(t)* behavior for recognition and prediction process represent dumping oscillations around normal value Z_0 (see Figure 2*a*).

Note that the prognosis represents a particular case of recognition problem (the recognition of the time-dependent process).

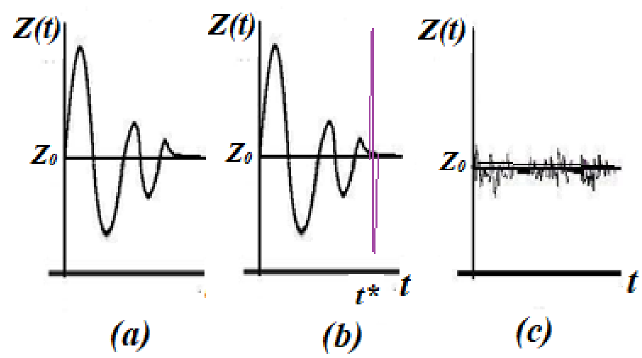

Figure 2. Typical patterns of the noise amplitude *Z*(*t*) behavior in the cases of (a) recognition procedure; (b) incorrect prognosis with sense of humor manifestation, and (c) aesthetic emotions ("*goosebumps*").

Special case of incorrect prognosis, which activates the sense of humor has been discussed in [13][14]. It arises when the examinee process seems familiar up to some moment *t**, but the next bulk of information appears to be once unexpected, but still well-known. This switches the recognition process to the other, also familiar pattern. It corresponds to the specific reaction of the system, that is, sharp up-down jump ("spike") in the noise amplitude, which could be associated with human *laughter* (see Figure 2*b*).

In [15], it was shown that perception of art calling for bright but unformulated emotions (the *goosebumps*) could be imitated by small *trembling* of *Z(t)* around Z_0 (see Figure 2*c*).

Note that two last examples represent in some sense a kind of stress behavior ("*smooth* stress"), which corresponds to somewhat extreme impressions.

In [14], the variation of *Z(t)* under external load was considered. It was shown that extremely high load results in specific behavior: irregular high-amplitude oscillations of *Z(t)* with high probability result in the fall to the abnormal stationary state $\{Z^*, \mu^*\}$, where $Z^* << Z_0$ and $\mu^* << 0$, that corresponds to deep depression or *coma*. These results coincide qualitatively with conclusions of [10].

Here, we put forward the following hypothesis. The panic mode could be imitated as follows. If the recognition process meets unexpected difficulties (without any external effect) while the problem should be solved *urgently*, *Z(t)* at the first stage increases (without oscillations) up to some critical value $Z^{**} >> Z_0$. High level of noise corresponds to super-mobilization of all the resources including self-excitation of so called "sleeping" neurons (never involved into training process before). Thus, at this stage increasing *Z(t)* value (negative emotions, i.e., anxiety, worrying, nervousness, etc.) does play positive (constructive) role. Then, this regime changes for chaotic "jumps" of *Z(t)* around Z** (see Figures 3*a*, 3*b*) that could be treated as *intellectual panic*. Indeed, if *Z(t)* achieves the value $Z^{**} >> \Omega_0$ (the rough value of "black" connections), then these connections seem to be broken and the noise dominates in RH. It results in chaotic self-activation of the neocortex neurons (variables H^0 and G^R) independently of any already learned patterns. This corresponds to "free wandering thoughts" discussed in Section II. The jumps in *Z(t)* correspond to the emotional (mood) jumps.

The decrease of *Z(t)* down to zero at some moment t** results in a deep long depression (see Figure 3*b*), which could be overcome only by external efforts (an analogue to medical intervention).

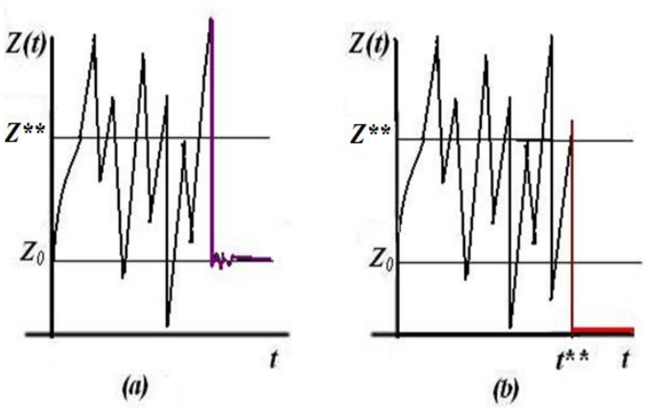

Figure 3. Typical behavior of *Z(t)* under the "intellectual panic" in the case of (a) "aha moment" and (b) deep long depression.

However, such mode should require significant amount of energy and thus, could not last long. It could stop either by sharp drop in *Z(t)* down to normal value Z_0, i.e., the peak of positive emotions (*aha!* moment, or *eureka!*) if rather "good" solution was found (Figure 3a), or by certain external (an analogue to *drug*) effect. Otherwise it could lead to deep depression as in Figure 3*b*.

IV. Conclusion and Further Work

Within NCCA, emotions are associated with the noise amplitude *Z(t)* derivative *dZ/dt*: increasing *Z(t)* (*dZ/dt*>0) corresponds to negative emotions (anxiety, worrying), while decreasing *Z(t)* (*dZ/dt*<0) corresponds to positive ones (satisfaction, relax). Note that negative emotions in normal cognitive process (such as recognition, prognosis, decision making, etc.) do play positive role increasing the activity in RH for generating several hypotheses on the given problem solution. Here, positive emotions also play positive role activating LH for hypothesis testing.

It is shown that under certain extreme conditions (such as the necessity of urgent solving any complex cognitive intellectual problem), normal functioning mode could be replaced by the extreme one. In this mode, increasing *Z(t)* up to some critical value Z** actually plays positive role resulting in mobilization of the latent resources (self-excitation of "*sleeping"* neurons in RH). Further increasing *Z(t)* up to values *Z(t)* >> Z** results in chaotic activation of neurons in RH, which provokes chaotic "jumps" of the noise amplitude *Z(t)*. This behavior could imitate the effect of *intellectual panic*, or "*throes of creativity"*.

In this paper, we have not considered possible effects connected with ratio of characteristic times τ^Z and τ^Ω for variation of noise amplitude and connection training, respectively. This ratio should control the process of creation of new connections between the sleeping neurons in the "*fuzzy set*" $\boldsymbol{H^0}$ thus resulting in new nontrivial images and solutions.

Also, we have not considered here the behavior of the neurotransmitter composition $\mu(t)$ at the *panic* stage. Apparently, this component should also demonstrate certain chaotic behavior, but with some time shift with regard to the noise amplitude *Z(t)*. This dynamical process deserves special study.

Moreover, variation of ratio of parameters Λ_0, Z_0, Ω_0, and Z** could lead to interesting effects and deserve additional study. In normal cognitive mode, these parameters are to be similar by the order of magnitude: $\Lambda_0 \sim \Omega_0 \sim Z_0$. Deviations from this ratio could result in some specific regimes as, e.g., "*mental rigidity"* [9] (poor dialog between hemi-systems) at $\Lambda_0 << \Omega_0$, or "*low creativity"* [24] at $Z_0 << \Lambda_0 \sim \Omega_0$, etc. Of course, all these effects require special study.

In addition, various combinations of parameters Z_0, τ^Z and μ_0, τ^μ could serve to reproduce the well-known Hippocrates classification of human temperaments (choleric, sanguine, melancholic, phlegmatic) and to reveal the correlation between the temperament and a tendency to a certain mode of panic behavior. But this is the subject for special study.

It should be noted that all typical patterns of *Z(t)* behavior discussed here represent the results of theoretical simulations. Apparently, clinical verification is needed. Now, we plan certain collaboration with Dr. Dibsburry from PsychPress (Talent Management Psychology, Melburn, Australia) and Prof. Bykov from Irkutsk State Medical University (Russia) to verify our hypothesis by tests and questionnairs. Possible collaboration with Kurchatov Research Center (Russia) on fMRI study of the people in panic state is also considered. However, all these problems require further work.

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