# About one of approaches for constructive modelling of functional systems and media

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**Abstract**

An abstract cellular model of distributed information medium is considered. The consideration is based on the concept of functional system participating in the interactive information exchange with the medium. Possibility for functional use of several scale level interactions between the system and medium is considered.

## 1. Introduction

The concept of functional media is applicable in very wide area of science [1]. There are such branches as currently intensively developing physics of nanostructures [2], physics of cooperative phenomena and phenomena of self-organization in semiconductors [3]. Regarding the concept of synergetics computer [1], one can conclude about main characteristics of information processing properties of these media. This characteristics is the cooperative processing yielded from the nonlinear and distant character of internal medium links.

A good example of such a medium is the cellular neural networks, which theory was introduced in [4], and practical applications presented in [5].

However, construction of this medium is based on the standard analogue circuitry. Active elements of medium are amplifiers, interconnected via nonlinear circuits and biased by a controlling voltage. The network was introduced as the parallel information processing device, which has the buses of information input and output. Due to the capabilities for the signal processing by the analogue and cooperative way in real time this network performs complicated and practically useful signal processing [5]. As it is shown in [5], the recognition of Chinese characters is one of the tasks solvable for this type of a functional medium when it has certain pattern of dynamics between its elements.

So as this medium is designed from the macro-elements, the pattern or form of dynamics in internal links can be set due to the needs of the particular function. This function is performed by the whole medium as the open system, as it has definite input and output channels and definite controlled pattern of internal dynamics.

However, another approach can present interest if one takes into account possible difficulties with adjusting of internal dynamics pattern in the medium and with information input and output. This approach appears if we consider the medium, structured on nanometer scale. Operation with processes in such structures needs take to account the quantum character of phenomena on that scale level [2]. By one's nature it cannot be directly and precisely controlled. The information input and output in and from such a medium possesses a character of conceptual problem. Such a condition appears also with an internal dynamics control for what few possibilities can be applied. One of them is the influence on general conditions applicable for the sample, such as the pressure, temperature, external electric and magnetic fields. Another one is the variability of sample preparation conditions.

The modelling approach, which has its main goal to suggest a solution toward a useful information processing in such a medium is a result of the following several steps of consideration. First is the formal description of functional system, which is part of a bounded medium. Desired behavior of the system is considered using the concept of distributed information processing in a scale of the whole bounded medium. Several analogies with physical examples are presented. Next are the interface possibilities for such a medium considered with the conclusion for synergetics modelling which takes to account mesoscopic parameters [1].

## 1. Interactive context in a functional system consideration

Let us consider the bounded medium in a general form of cellular automata presentation defined by:

$$X_i^t = F(X_i^{t-1}, \{X_q^{t-1}\}) \quad (1)$$

where $X_i^t$ $-$ is a value of certain parameter of the cell with number $i$ on the step $t$ having a $\{q\}$ set of neighbors. It is assumed, that geometry of the medium is like a spherical one. The cellular field is uniform and without selected cells on its borders. In this general form of notation function $F$ determines the concrete form of internal collective dynamics in medium.

One of the purposes of this paper is to describe a criterion, which will help to construct this function applicable from the point of view of information processing in the medium. For that we have to consider relationship of selected cellular objects or systems with ones' neighbors and medium.

Speciality of cellular automata is in the collective character of any change in ones condition. However, the modification of a chosen cell condition can be reflected on the condition of a distant cell on a certain time step after event. Also the strength of this action can vary with the distance and the condition characteristics.

Regarding parameters of internal dynamics we can conclude, that for the selected set of $N$ cells $\{A_N\}$ with the certain conditions on its borders there is the certain conditions of cells in neighborhood and in the current moment of time. Due to the action of cells' condition on the border out, and as the medium is bounded and close, this reflection of border condition will move in transformations and come back in a certain form in consecutive steps of time.

These simultaneous processes are to be regarded together with ones' action on internal dynamics of a chosen part of medium.

Let us consider the condition of the system border as a pattern, which has dynamically allocated role of one's variables. The latter ones are presented by subsets of $n < N$ cells dependent on the form of information presentation. The preferable form is relative, which means the equivalence of subsets $\{A_k\}, k < n$ to subset $\{A_i\}, i = k; i + k \leq n$ in the sense of information meaning if a group arithmetic operator can be applied for the subsets:

$$A_{kj} = \hat{f}(A_{ij}), j \leq k. \tag{2}$$

These subsets can differ in the sense of action of an interfacial associativity operator, considered together with the dynamic properties of the system. This operator is determined as reflecting the above mentioned two properties of the medium. First is the property to distribute the information contents reflecting the system borders' condition in a scale of the whole bounded medium. The second property characterizes possibility for the functional system to interact or associate the distributed contents to its border relatively to the condition of the border.

The operator maps the border pattern onto itself, adding the small additions for parts of $\{A_k\}$ relatively and associatively to the values of neighboring $\{A_i\}$ and vice versa with varying $k$ and $i$ toward ones' averaged values in changing pattern $\{A_n\}$.

$$A_n^{t_c} = \hat{\phi} A_n^{t \not\equiv t_c}. \tag{3}$$

where $t_c$ is the chosen moment of time, $t \not\equiv t_c$ is the time of this pattern existence and changing.

The latter changes can occur under the local neighbors' action not linked directly with described above property. The example of such change can be found in similar algorithm of the experiment described in [9].

Briefly and by the author's opinion, the essence of the experiment is in the following. Phenomenon of distributed recording of condition of self-organizing system in externally from system located structures is investigated to outline the sensitivity of self-organizing system for interaction with these structures.

The system is a volume with a heated viscous liquid, in which one can observe existence of self-organized dissipating structures [9]. From outer medium the system can receive perturbations in the form of heat beam and in the form of interaction with the structures, which are called reflecting structures containing information about the form of dissipating ones. The reflecting structures are produced in interaction with the dissipating ones as the soft plates being put on the top of the liquid in the volume. As plate is sensitive for the temperature field, it changes its form copying surface picture of the structures in the flow. For different regimes of convection flow the different reflections of dissipating structures can be received.

By this way information about certain condition of the system is recorded in the plates and then is brought away. Next condition of the system is changed by perturbation from the heat beam. In the model terms the system receives action from local neighbors and its condition is changed. In cited experiment and system, the form of dissipating structures is changed. In the following step this form returns to the previous one after reflecting structures come back and act on the system as plate placed again on the top of the volume. By this way the associative memory can be realized [9].

As one can see from this example, the action on the source system was done on its border. Also the reflecting structures were modulated by the border condition. As it has been described above for the cellular field, the reflecting structures come back after a certain delay, while the system could be changed. The delay in the cellular field is dependent on the number of neighbors $\{X_q^{t-1}\}$ (1) acting directly on the chosen cell, and on the function $F(X_i^{t-1}, \{X_q^{t-1}\})$, which determines dynamics by which this direct action propagates in the medium.

Coming to the systems with more complicated internal dynamics (e.g. with interaction with external perturbations) one can interpret the results, presented in [6] from the position of the approach.

It was shown in [6], that current behavior of chaotic system can be synchronized with its past behavior, recorded previously in memory. This is achieved by a small self-controlling feedback perturbation in the form of difference between the current and past output signals. The synchronization is appeared as the possibility to force the system to repeat exactly its past behavior. It is assumed that the minimal number of controlled variables has to be equal to the number of positive Lyapunov exponents of the system [6].

The difference between current and past output signals has direct meaning in the description of interfacial associative operator $\hat{\phi}$. The associativity in [6] is not considered, because the behavior of controlled variable is recorded by conventional way in a computer memory. In the case of distributed recording of border subset condition, it is necessary to consider the way, by which these recorded contents can act back on the system. The associative attachment of the contents to the primary pattern of variables is consequence of the $\hat{\phi}$ operator action.

Let us consider one of the form of more definite presentation of operator $\hat{\phi}$ in the following simulation of the dynamic system. As it is mentioned in [7], the behavior of cellular automata can lead to the limit points, circles, attractors and chaotic behavior of dynamic systems. Regarding the functional system to be described as the part of larger medium, one has to simulate it by the system of ordinary differential equations, which has complicated character of external perturbations in the sense of controlling action presented in [6]. The form of equations reflects internal properties and internal dynamics of the system. The form of the perturbations reflects the action of operator $\hat{\phi}$, applied to the borders of the functional system, and equivalently presented in the disturbances on the system variables in the following notation.

$$\dot{y} = P(y, \mathbf{x}) + \mathbf{K_y}(y, \mathbf{x}) < \tilde{y}_{ap}(t, \mathbf{x}) - y(t) > \tag{4}$$
$$\dot{\mathbf{x}} = \mathbf{Q}(y, \mathbf{x}, \mathbf{K})$$

where $y(t)$ is a variable, correspondent to the subset of the border pattern $\{A_i\}$ receiving an associative action relatively to values of subset $\{A_k\}$ presented by vector $\mathbf{x}$. The values $\tilde{y}_{ap}(t, \mathbf{x})$ are taken correspondent to the values of vector $\mathbf{x}$. Functions $P(y, \mathbf{x})$ and $\mathbf{Q}(y, \mathbf{x}, \mathbf{K})$ reflect the internal dynamics and properties of the system. Function $\mathbf{K_y}(y, \mathbf{x})$ is a projection of a vector function reflecting the nonlinear character of associative relationship between the system and medium. The possibility for every variable of the system to receive the perturbation associatively linked with the values of other variables is reflected by dependence of function $\mathbf{Q}$ from function $\mathbf{K}$. This means that all variables from the vector $\mathbf{x}$ can take place of variable $y$ in the first open notation.

The case of several controlled variables has been regarded in [6] without addition of associative links between them. In that case the function $\mathbf{K}$ degenerates into constant. The difference between current and past values of controlled variables is taken directly and continuously in the time after delay. The above written averaged difference $< \tilde{y}_{ap}(t, \mathbf{x}) - y(t) >$ is taken due to the moments of time, when the values of the variables, chosen by function $K_y$ from the vector $\mathbf{x}$ equal with certain precision to ones' values in current moment of time. By this way, these variables become dynamic basis for the associative recall acting on the others. Due to the nonlinear character of associative relationship with the medium, the role of variables can be dynamically changed.

This dynamics also reflects the speciality of modelled functional system construction. The above mentioned pattern of border cells can possess varying efficiency of associative interaction with medium dependent on current information content of the pattern and its involvement in internal dynamics of the system. The function performed by internal processes in the system can be regarded as an associative one, controllable from the medium due to the interaction through the border.

**2. The functional system formation and its several scale level presentation in the medium**

The above presented consideration of one of possible dynamics in the cellular field is characterized by the step into a functional medium. That step moves attention from the function performed by such distributed media as the cellular neural networks [4-5], Hopfield neural network and other [10], which realize desired function as unit, to subunits in the medium. The subunit also can be regarded as able to perform an intelligent and complicated function in the context of described above exchange with the medium. Main difference is in the change of internal functional system dynamics role.

While the main efforts in work with neural network models are directed to the algorithms and approaches to store information in network structure for purposes of following pattern recognition and other functions [10], this approach extends the area of information localization out from the system and moves focus of consideration on the properties of internal functional dynamic of system to be reflected and controlled in an associative exchange with the medium.

The system has to be sensitive to the information contents, coming from the medium and acting as ones associative respond to the current condition of the system border. Due to the property of internal dynamics of the system, that respond has to act associatively and direct evolution of the system adaptively to its current condition.

This general picture of internal processes in a close bounded medium has its main goal to be a criterion for the construction of cellular laws of interaction (1). Existence of distributed reflection of the system condition in the medium has to be based on the applicability of a Guigence principle [8]. As it is implied in [8], existence of steady analyzed in a cellular field structures is linked with the hidden mechanism of action from lines of a constant phase. These lines illustrate propagation of reflecting information with very high speed in network, regarded in [8]. Regarding action of this principle in more complicated cellular model, it can be concluded about several values of energy and speed for reflecting waves determined by function $F$ (1). This difference in a delay and strength of reflection coming back can dedicate different impact on the internal dynamics of the functional system. Its existence in the form of the steady objects analogous to described in [8], but having more complicated internal structure and dynamics can be also linked with that difference. Existence of such complicated structures, which associatively support the link between ones' parts in unity has to be based on scaling properties of the wave propagation in the medium. Before coming back, the reflecting waves or reflecting structures have to pass transformations. As primary structure is part of the medium, it is logical to conclude about scale transformation of reflecting structures going out from one in the medium and coming back from the medium. A concrete form of these transformations and concrete form of interactions with the primary structure is to be investigated in a computer simulations of the constructed cellular space.

Experimentally it looks possible to interfere on one of these transformation levels, and by this way create the functional system itself and mechanism of communication with it simultaneously. By this way, the information input and output on processes in nanometer scale structures hypothetically can be built. For example, such an interference on the macro level of distributed nanostructured film can be organized by applying of current through the metal contacts or electrodes of relatively large geometry and size. By analysis of supposedly correlated current fluctuations on contacts, the dynamic and information processing properties of such medium can be investigated.

The main difficulty in such an experiment is in the need of a clear understanding of information processing, which can occur in the medium without any control. Does the medium possess this complicated internal dynamics, which allows appearance and existence of objects supporting themselves in interaction with the other moving objects, which correspond to reflecting structures? Do the firsts objects possess complicated internal dynamics reflected on latter structures? Is it possible to interact with these structures to receive the functional respond and useful information processing on the primary level?

These questions are difficult to answer without comprehensive computer simulation of mesoscopic processes in investigated medium.

However, such a hypothesis of the existence of these several scale levels of dynamics in the bounded medium can be profitable for more clear understanding of microscopic phenomena in the self-organization.

If one considers cells in a volume with heated liquid as an intermediate form of reflecting structures, it can be supposed an existence of the other ones being hidden by observable structures in this volume. These structures of another scale level could have another form of existence and by this reason could not be directly observable. If direct the attention on other side of scales, one can conclude about some form of structuring in the scale of the microscopic volumes of liquid.

The latter hypothesis has its particular support in the consideration of entropy in the volume with the turbulent flow [11]. It is implied in a preface discussion in [11], that increase of order with the transfer to a turbulence is linked with the energy of disordered heat motion of liquid molecules transferred to the energy of a coherent motion of groups of molecules. Regarding discussion in [11] of the fluctuation role in the self-organization, one can interpret this process of order's increase as a result of competition between the fluctuations on the level of microscopic volumes of liquid.

By the form of the process it looks like an associative recall. As it was described above, the dynamical existence of relatively steady structure can be supported from outside by the action of ones reflecting structures being moved in the medium. So as the size and shape of the medium allow preferable existence of the particular form of moving structures (like the waves with a certain wave vector in a resonance system), not every micro volume of liquid with certain its characteristics can receive the support, grow and appear as the structure of self-organization. Dependence on regimes or on characteristics of energy flow is significant for this. If one considers the $S$ or $N$ shape nonlinearities investigated in semiconductors [3], one can interpret them from position of the approach as reflection of creation in a system the above mentioned reflecting structures.

By this way, the self-organization can be divided on stages and levels with associative character of ones' relationships. If we have picture of self-organization on one of the levels, it is obvious, that the exchange between levels exists. It is logically to suppose, that form of the motion on the other levels can be hidden or look as disorder. Regarded mentioned above example of the turbulent motion in a flow of a liquid, it can be concluded about applicability of described above approach for the mesoscopic simulations [1] of the processes in this medium. Together with accounting of different microscopic parameters of the liquid the associative addition for statistical modelling could help to make the simulations more precise.

**Conclusion**

To summarize the above presented description of the approach, it is necessary to note, that one's proof of applicability for construction of useful microscopic model of a distributed information processing medium should be found in computer simulation.

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