Knowledge Manifestation in Biological Systems Dynamics

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Abstract
Recognizing anticipation as a specific form of knowledge and taking specific form of knowledge realization in a physical system (a program for Feynman's universal reversible quantum computer) one gets a definite algebraic property of quantum system's dynamics, which appeares to be closely related with characteristic features of biological systems. This means that physical description of biological systems at quantum level must anyhow contain explicit logical component evoked by the system's intrinsic knowledge. On physical level the fact of such knowledge existance manifest itself in global algebraic properties of its dynamics. Evolution of biological systems in such approach turns out to be an evolution of certain set of interaction constants of system's hamiltonian which makes it possible to implement logical operations as summands of the system's evolution operator.

Keywords: knowledge, anticipation, quantum mechanical computer, Weyl algebra, biological evolution

1 Introduction

The concept of anticipation as an emergent property of a system, which occurred in system's reaction on changes of surrounding and enabling system to act in accordance with its potential future by means of working out the corresponding aim, requires detail elaboration in respect to biological systems.

The most popular paradigm in the description of self-organising systems at present is the structure creation as a consequence of the loss of stability of less organised state of opened system under the certain external conditions and its transition to more organised stable state. In the framework of this paradigm many characteristic features of complex systems are successfully explained (their purposefulness, learning ability, evolution). The essential feature of this approach is that it is based on instability of some limit sets in the system phase space. This instability is usually understood as the instability of certain trajectories of the system described in the language of classical physics.

Nevertheless, the fundamental level of the description of any system is the quantum mechanics level. It is well known that temporal evolution of quantum system in the corresponding Gilbert space of states is stable due to the fundamental principle of superposition of quantum theory. Because the abandon a principle of superposition does

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not seem to be acceptable, the problem of consistency of classical description of highly organised systems and quantum sight on reality is arisen.

The necessity of quantum approach to complex systems study was proved by B.Mitugov [1], who showed that every concept of probability, which is the corner stone of self-organisation paradigm, may be defined properly only on quantum mechanical basis. We hope the achievements of classical approach to complex ordered systems may be brought into agreement with quantum language by the developing of quantum mechanical models of the dynamics of knowledge in such systems.

2 Ontological aspect

The matter is that intuition to this or that kind of knowledge is inherent in the very concept of anticipation - the last is the knowledge about the future events namely. Knowledge differs from information as such because the first contains value component. From the ontological viewpoint knowledge is a characteristic of being-for-self or *intelligentia* while information is an objective characteristics of being-as-such, measure of its variety. Information becomes knowledge only when involved in *intelligentia* sphere. Then, anticipate systems must be of some kind of *intelligentia.*

In theoretical biology this caused continuous discussions on reductionism, teleology, vitalism and organic purposefulness. These are still go on, concentrating on the admitting or non-admitting the existence of some kind of rationality in biological systems which is considered to be external (God) or internal (rudiments of consciousness) with respect to them. While, *intelligentia* does not obligatorily assume the level of rationality, as it was splendidly shown by great Russian philosopher A.F.Losev in the 20-ies of XX century in his remarkable work "The Philosophy of Name" [2]. His consideration was based on dialectics of sense as a symbolic unity of knowledge and existence and may be briefly presented as follows:

Being-beside-self. Every elements of such being is external to any other. Such being is not able to carry out any sense in it.

Physical thing is the first integration and surmounting of this absolute discretion of being. Physical world is the external integration of internally disintegrated elements of being, they obey to some sense assembling them into a whole out of shapeless overspreading plurality. The whole can not be derived from its separated parts, it is a specific sense-induced arrangement of being, which Losev called as **physical** ενεργημα. Physical thing is the whole, hence it is physical ενεργημα at the same time, which is not physical as such and related to the area of sense. Sense and materiality are both necessary for actual existence of physical thing.

Considering sense as a condition for the reality of every thing requires the inclusion of

being-for-self category into description of thing. This category represents the essence of knowledge or *intelligentia.* Physical ενεργημα is the lowest degree of intelligentia, without it the existence of whole is impossible. According to Losev, physical ενεργημα is the knowledge of elements about each other without knowledge of any elements about itself and without knowledge of the fact that they know each other and do not know themselves.

The next level of *intelligentia* is Losev's **organic** ενεργημα or the principle of irritating organism. That is the knowledge of one thing about the other thing from its external side without knowing itself and without knowing the fact that it knows the external thing and does not know itself.

Note that in the framework of both these ενεργημα's, which are sufficient to define the specificity of living being, *intelligentia* does not reach the levels of consciousness or rationality. Knowledge is "dissolved" in the dynamics of system, coincides with that and remains be the non-physical component of the system simultaneously. How can this situation be expressed in physical terms?

3 Physical description

Physical object in which we have to define knowledge is the system of atomic nuclei, electrons and electromagnetic field considered from quantum mechanics point of view.

Any application of quantum mechanics requires acceptance of some logical paradigm and it is that which causes continuous debates in foundations of quantum physics. The main result of them is the development of specific quantum logic [3,4] and specific logic of quantum computing [5]. As logic one shall mean not only the logic of investigator, but logic of the system itself, which is evoked by the type of its intrinsic knowledge. In accordance with H.Putnam's thesis logic has constituent physical importance for quantum mechanics as space-time geometry for gravitation theory [6].

We assume the simplest specific definition of knowledge as certain set of logical operations - **a program** - and study closed non-relativistic molecular system of finite volume with Hamiltonian $\hat{\mathbf{H}}$ and discrete energy spectrum. Arbitrary state vector $|\xi\rangle$ of such system may be represented as a superposition of states $|L\rangle$ with definite energy:

$$|\xi\rangle=\sum_L |L\rangle\langle L|\xi\rangle, \tag{1}$$

where

$$\hat{\mathbf{H}}|L\rangle=E_L|L\rangle, L=0,1,\ldots,\infty. \tag{2}$$

Let our system be consisted of N nuclei and M electrons with Coulomb interaction between them. Without loss of generality the non-relativistic Hamiltonian of such system may be represented as [7]

$$\hat{\mathbf{H}} = \hat{\mathbf{T}}_\mathbf{N} + \hat{\mathbf{T}}_\mathbf{e} + \hat{\mathbf{V}}_\mathbf{N} + \hat{\mathbf{V}}_\mathbf{e} + \hat{\mathbf{V}}_{\mathbf{N}e}, \tag{3}$$

where operators $\hat{\mathbf{T}}_{\mathrm{N}}$ $(\hat{\mathbf{T}}_{\mathbf{e}})$ describe the kinetic energy of nuclei (electrons), $\hat{\mathbf{V}}_{\mathrm{N}}$ $(\hat{\mathbf{V}}_{\mathbf{e}})$ - potential energy of nuclei (electrons) electrostatic interaction, $\hat{\mathbf{V}}_{\mathrm{N}e}$ - interaction between nuclei and electrons:

$$\hat{\mathbf{T}}_{\mathrm{N}}=\sum_{J=1}^{N}\frac{\vec{\mathbf{P}}_J^2}{2M_J}; \tag{4}$$

$$\hat{\mathbf{T}}_e=\sum_{j=1}^{M}\frac{\vec{\mathbf{p}}_j^2}{2m}; \tag{5}$$

$$\hat{\mathbf{V}}_{\mathrm{N}}=\frac{1}{2}\sum_{\substack{I,J=1\\ I\neq J}}^{N}\frac{Z_I Z_J e^2}{\left|\vec{\mathbf{R}}_I-\vec{\mathbf{R}}_J\right|}; \tag{6}$$

$$\hat{\mathbf{V}}_e=\frac{1}{2}\sum_{\substack{i,j=1\\ i\neq j}}^{M}\frac{e^2}{\left|\vec{\mathbf{r}}_i-\vec{\mathbf{r}}_j\right|}; \tag{7}$$

$$\hat{\mathbf{V}}_{\mathrm{N}e}=-\frac{1}{2}\sum_{I=1}^{N}\sum_{i=1}^{M}\frac{Z_I e^2}{\left|\vec{\mathbf{R}}_I-\vec{\mathbf{r}}_i\right|}; \tag{8}$$

We introduced here the masses, electric charges, momenta and radius vectors of nuclei $\left(M_J, Z_J e, \vec{\mathbf{P}}_J, \vec{\mathbf{R}}_J, J=1,\ldots,N\right)$ and electrons $\left(m,-e,\vec{\mathbf{p}}_j,\vec{\mathbf{r}}_j, j=1,\ldots,M\right)$ correspondingly.

In secondary quantization representation, an arbitrary state of the system may be expanded into a series of single-particle states of nuclei and electrons symmetrized according to Pauli's exclusion principle. Using the time-dependent Heisenberg's operators of creation $\hat{A}_s^+$ and annihilation $\hat{A}_s$ of nucleus in single-nucleus state $|s\rangle$ and Heisenberg's operators of creation $\hat{a}_\alpha^+$ and annihilation $\hat{a}_\alpha$ of electrons in single-electron states $|\alpha\rangle$, an arbitrary state (1) may be represented as

$$|\xi\rangle=\sum_{\substack{s_1,\ldots,s_N\\ \alpha_1,\ldots,\alpha_M}} C_{\alpha_1,\ldots,\alpha_M}^{s_1,\ldots,s_N}\hat{A}_{s_1}^{+}\cdots\hat{A}_{s_N}^{+}\hat{a}_{\alpha_1}^{+}\cdots\hat{a}_{\alpha_M}^{+}|vac\rangle, \tag{9}$$

where $|vac\rangle$ is time-independent vacuum state of the system. Secondary quantized Hamiltonian from eq.(3) takes now the form

$$\begin{aligned}\hat{\mathbf{H}}=&\sum_{s,s'}H_{ss'}\hat{A}_s^{+}\hat{A}_{s'}+\sum_{\substack{s,s',\\ p,p'}}Q_{sp,s'p'}\hat{A}_s^{+}\hat{A}_p^{+}\hat{A}_{s'}\hat{A}_{p'}+\sum_{\alpha,\alpha'}h_{\alpha\alpha'}\hat{a}_\alpha^{+}\hat{a}_{\alpha'}+\\ &+\sum_{\substack{\alpha,\alpha',\\ \beta,\beta'}}q_{\alpha\beta,\alpha'\beta'}\hat{a}_\alpha^{+}\hat{a}_\beta^{+}\hat{a}_{\alpha'}\hat{a}_{\beta'}+\sum_{\substack{s,\alpha,\\ p,\beta}}W_{s\alpha,p\beta}\hat{A}_s^{+}\hat{a}_\alpha^{+}\hat{A}_p\hat{a}_\beta\,.\end{aligned} \tag{10}$$

If all summands of eq.(10) not contained the electron-nucleus interactions were denoted by $\hat{H}_0$, then

$$\hat{\mathbf{H}}=\hat{H}_0+\hat{\mathbf{V}}_{\mathbf{Ne}}\ . \tag{11}$$

In Dirac's representation described by the transformation of the operators of observables and state vectors of our system according to

$$\begin{aligned} &\hat{F} \rightarrow \breve{F} = e^{\frac{i}{\hbar}\hat{H}_0 t}\,\hat{F}\,e^{-\frac{i}{\hbar}\hat{H}_0 t}\ ; \\ &|\xi\rangle = |\xi\rangle_D = e^{\frac{i}{\hbar}\hat{H}_0 t}|\xi\rangle\,, \end{aligned} \tag{12}$$

The operator of interaction will determine its time evolution:

$$|\xi,t\rangle_D=\hat{T}e^{\frac{i}{\hbar}\int_{t_0}^{t}\breve{V}_{Ne}dt}\,|\xi,t_0\rangle_D, \tag{13}$$

where symbol $\hat{T}$ means the time ordering, and

$$\breve{V}_{Ne} = \sum_{\substack{s,\alpha,\\ p,\beta}} W_{s\alpha,p\beta}\breve{A}_s{}^+\breve{a}_\alpha{}^+\breve{A}_p\breve{a}_\beta\ . \tag{14}$$

Introducing nuclear operator

$$\breve{G}_{\alpha\beta} = \sum_{s,p} W_{s\alpha,p\beta}\hat{A}_s{}^+\hat{A}_p \tag{15}$$

and supposing it to be non-zero only for neighbouring transitions $\alpha \rightarrow \alpha \pm 1$, interaction eq.(14) may be rewriting as

$$\breve{V}_{Ne}=\sum_{\alpha=1}^{\infty}\breve{G}_{\alpha,\alpha-1}\breve{a}_\alpha{}^+\breve{a}_{\alpha-1} + \textit{hermitian conjugation.} \tag{16}$$

The last expression formally coincides with R.Feynman's Hamiltonian of **reversible quantum mechanical computer** [8]:

$$\hat{H}_{Feynman}=\sum_{i=0}^{k}q_{i+1}{}^+q_iA_{i+1} + \textit{hermitian conjugation.} \tag{17}$$

Feynman's Hamiltonian describes quantum system containing the n-positioned ***register*** (n register atoms) and ***program pointer*** with (k+1) nodes (program atoms). Operators q_i^+, q_i in eq.(17) are the creation and annihilation operators for i-th two-level program atoms while operators A_i acting on the register states realise *simultaneously* the logical operations of Boolean algebra. Feynman considered register as the set of n two-level atomic systems and proved the negation operation NOT and all other logical operations as well may be realised by means of the creation and annihilation operators of the register atoms, in terms of which A_i from eq.(17) are proposed to be represented.

Evolution of Feynman computer is determined by evolution operator

$$e^{\frac{i}{\hbar}\hat{H}_{Feynman}t} = 1 + \frac{i}{\hbar}\hat{H}_{Feynman}t - \frac{\hat{H}_{Feynman}^2}{\hbar^2}t^2 + \ldots \tag{18}$$

If all nodes of program pointer are not occupied (program atoms all are at corresponding vacuum states $|0\rangle_i$), then the evolution operator turns out to be identity and there is nothing happened in the system.

If only one node of program pointer is occupied, (one program atom is at the state $|1\rangle$), then such situation remains for all times.

Supposing only one node have to be occupied at any time, Feynman proved: given zero program node is occupied at zero time and k-th node occurs to be occupied at some other time, then register state will be multiplied by the operator $M = A_k \cdots A_3 A_2 A_1$ to that time. This means that the definite operation of Boolean algebra corresponding to operator M will be realised in the computer simultaneously. The sequence in which the excitation transited from one program atom to another, is arbitrary excepting the (m+1)-th atom being excited *if* m-atom having just been excited sometimes early at least once.

Feynman in [8] does not discussed problem of physical realisation of his model but, in our opinion, his approach has direct relation to anticipate systems' theory and modelling biological systems. More closely, if program is realised in any molecular system, one may consider it as the system with knowledge, and that is just what is necessary for arising Losev's *intelligentia* in that system, given the interaction of the system with surrounding is informative.

The comparison of eqs.(16) and (17) shows that the form (16) chosen for interaction presupposes identification of program pointer and register with electronic and nuclear subsystems correspondingly. Lets study what requirements must be specified for nuclear operator $\breve{G}_{\alpha\beta}$ to make interaction (16) be capable to describe the Feynman's quantum mechanical computer at least in principle.

I. In Feynman model the negation operator NOT (one of the binary logic main operations) is represented by the linear combination of the creation and annihilation operators for register atom states. In our notation this means

$$NOT \leftrightarrow \breve{A}_p^+ + \breve{A}_p \,. \qquad (19)$$

It is easy to see that pure Coulomb interaction between nuclei and electrons, bilinear with respect to $\breve{A}_p^+$ and $\breve{A}_p$ (look at eq.(15)), does not permit one to satisfy eq.(19) choosing some interaction constants $W_{s\alpha,p\beta}$.

Interaction between electrons and nuclear collective excitations are quite appropriate in this case. Their derivation from Coulomb interactions is based on the existence of some kind of equilibrium structure of the molecular system, the deviation from which is described in collective co-ordinates. The negation operation eq.(19) may be realised, for example, in the case of Fröhlich Hamiltonian describing the interaction between electrons and nuclei oscillations near their equilibrium positions:

$$\hat{H}_{Frohlich} = \sum_{\alpha,\beta,n} Q_{\alpha\beta n} \cdot \hat{a}_\alpha^+ \hat{a}_\beta (\hat{B}_n^+ + \hat{B}_n), \qquad (20)$$

where $\hat{B}_n^+, \hat{B}_n$ are phonon creation and annihilation operators, $Q_{\alpha\beta n}$ - interaction constants depending on substance structure. Note that it is Fröhlich Hamiltonian, which forms the basis of superconductivity description. This phenomenon is considered to be the most vivid exhibition of physical system wholeness by many physicists (according to Losev, wholeness is physical ενεργημα, i.e. the manner how physical thing appears in the spheres of sense). Our approach makes correct the question if superconductivity phenomenon is a manifestation of some logic occurring through the favourable set of interaction constants. The detailed discussion of the problem would lead us far away from the topic but it is worth reminding that Shrödinger [9] and later Pattee [10] paid attention to the possible fruitfulness of drawing parallels of superconductivity and living matter.

II. The "cyclic recurrence" of atomic states of the register is another important property of Feynman's model. He assumed the conditions $A_s^+|1\rangle_s = |0\rangle_s$; $A_s|0\rangle_s = 0$, which give

$$(A_s^+)^2 \equiv 1; \; (A_s)^2 \equiv 0 \,. \qquad (21)$$

Hence , the associative algebra generated by the elements of Weyl algebras of register atoms $\{1, A_s, A_s^+\}$, occurs to be **finite** algebra with (3n+1) generators $\{1, A_s, A_s^+, A_s^+ A_s\}$. Then, evolution operator of the register state is an element of this algebra and may be represented now as a finite linear combination of terms having form

$$\prod_{s=1}^{n}\left(f_1^{(s)}(t)+f_2^{(s)}(t)A_s^{+}+f_3^{(s)}(t)A_s+f_4^{(s)}(t)A_s^{+}A_s\right) \tag{22}$$

with time-dependent coefficients, and all logical operations of the program as well.

Seems, it should be supposed that the occurrence of knowledge in the system is reflected in its dynamics as the algebraic property of dynamical varieties, which restricts the possible ways of system's evolution. For example, such restriction is possible due to the reduction of generally numerable-infinite associative algebra to the finite one. Given the appropriate initial state, the evolution of "reduced" system takes place in narrow region of state space, and what is more, the initial correlations decay very slowly if at all. This property of "reduced" systems seems make it possible to formulate properly the concept of **creods** as the channelled ways of molecular transport in living substance, which was introduced to theoretical biology by Waddington [12] to stress the high level of its microscopic organisation. Various echo effects [11] occur in such systems too.

4 Biological meaning and prospects

Fast reconstruction of electronic "program pointer" with respect to more slow nuclei motions change the system program in accordance with the influences of surrounding. That is why these influences turn out to be informative. Electromagnetic fields may play an outstanding role in such information transfer due to the fact that interaction of photons with electrons has the same shape as eq.(15) with phonon operators replaced by photon ones. Such reconstruction of electron subsystem leading to "reprogramming of molecular computer" seems to be responsible for the effect of mutual "recognition" of biomolecules, as in enzyme-substrate interactions.

Evolution of biological systems in such approach turns out to be an evolution of registers and programs contained in living substances. Moreover, life origin itself is connected with the realisation of certain set of interaction constants $Q_{\alpha\beta n}, W_{s\alpha,p\beta}$, which makes it possible to implement logical operations as summands of evolution operator.

The enormous reduction of information in the transition from associative algebra with numerable-infinite number of generators to the algebra with finite one in the presence of knowledge seems up to make it possible to clarify main characteristic properties of anticipate systems.

Thus, recognizing anticipation as this or that form of knowledge in the spirit of A.F.Losev's philisophy and taking a specific form of this knowledge realisation in physical system (program for the Feynman's universal reversible computer), one gets a definite algebraic property of system dynamics, which in its turn appeares to be closely connected with some characteristic feature of biological systems. In our oppinion this means that physical description of biological systems at quantum level must anyhow contain explicit logical component.

Posessing its own logic, the system prescribes the logic of its investigation. The most important component of this "external" logic is the searching for the global generative characteristics, determining the holistic features of the system dynamics. That is why the symmetric and topological approaches are of great importance for modern quantum description of complex systems. Only after the determination of global properties the problem of their dynamical realisation on microscopic quantum level and the problem of the most suitable material for such realisation is setting up.

At present paper we confine the study of logic to the level of finite-order logic, on which knowledge may be represented as an algorithm. Being applicated to anticipative systems such as biological organisms, this restriction is relevant if the algorithm concept is broader than any Turing machine. The reason for that conclusion is the peculiarity of information organisation of biological systems, for which the functional integration of sensor and information-processing elements is characteristic.

On the organism level the excitation of sensoric modalities or irritation directly affects not only the "data region" states of the programm processed, but the states of processor elements themselves too. Turing algorythms are really based on recoursive definition of calculated function. If the state of processor element changes due to external action, another function is to be calculated. Only the result of calculation enables us to judge what function has been calculated with some extent of certainty. It is evident that this situation can not be described by any Turing machine. Than, it seems promising to study how the system's intrinsic knowledge manifests itself in the dynamics of the system, if it is represented by some incursion logic according to D.Dubois [13] rather than a Turing machine. Namely, we suppose the processor elements of the system in the absence of the external influence are performing some cyclical computation (basic cycle). Under such influence the transitions of some of the processor elements to other states occur. As a result the basic cycle is broken off. Discrepancy between the results of the running process and basic cycle characterises the external factor. It is task of the system activity to restore basic cycle. On the physical level this restoration implies the realisation of some quantum analogue of classical phase space attractors in the system Gilbert space. The restoring algorithm lenght is a measure of the external factor complexity according to A.H.Kolmogorov's definition, while the algorithm of restoring itself is a certain incursion algorithm [14]. It resolves typical incursion problem and can not be represented by Turing machine. Anticipation in such system manifests itself as a correspondence of the restoring algorithm with external factors. In biological terms basic circle represent vital activity of living system while the restoring algorithm - its psychic or mental activity and subjectivity in general.

To develop the quantum mechanical model of such systems the algebraic and quantum logic interpretations of quantum mechanics must be used supplemented by both classical and quantum information processing theory [15]. As a physical realisation of their basic cycles the Berry's phases [16] are promising in particular.

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