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Time, reflectivity and information processing in living systems: a sketch for the unified information paradigm in biology

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Abstract

The recognition activity of biomacromolecules based on quantum non-demolition measurements is regarded as the basis of information processing. Reflective arrows in the set of mappings appearing from quantum measurements correspond to the Gödel numbers created inside a system overcoming its incompleteness. Temporal evolution is a consequence of contradictory statements about the whole system in which a reflective arrow is both an element of the system and its signification. It results from the solution of a paradox in which the system generates new descriptions non-deducible from its previous states. The active combinatorial process of self modification of information, being an internalized language game, allows a system to create Gödel numbers. The whole system is constructed according to percolating coherent events, providing 'vertical' self-assembly that is predetermined by the encoding and internal language games.

Keywords: Incompleteness; Information; Language game; Quantum measurements; Reflectivity; Time; Topoic logic

1. Internal measurements and biological information processing

Information transfer in biosystems is based on fundamental properties of biomacromolecules. Their recognition activity is provided by low energy dissipation during registration of specific weak forces. This is described in quantum mechanical formalism as quantum non-demolition measurement (Witten, 1982; Igamberdiev, 1993).

Measurement represents a reduction in the field of potentialities and it can be considered as an important precondition of semiotic structures and information processing. In the internal measurement process the system is subdivided into two subsets: one controlling and the other being controlled (Igamberdiev, 1992). The controlling (information) level gives the appearance of placing extra restrictions (constraints) on the system, encoded in the internal description, which determine the 'individuality' of the system. These internal restrictions can be conceived of as 'arbitrary' in relation to physical laws. Measurement itself is a

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non-formal process, but its results are symbols that can be used in a formal system as information (Pattee, 1989). It forms a specific mapping in which recursive ('calculation') procedures can be realized, and the set of these mappings (i.e. of logical elements constituting a formal-logical system) underlies concrete biological organization.

The emergence of reflectively autocatalytic sets of polypeptides can be regarded as an essentially inevitable collective property of any sufficiently complex set of polypeptides (Kauffman, 1986). The set of catalysts realizing specific reactions when it is large enough can generate reflective arrows, i.e. the catalysts can attain properties of reflecting themselves (i.e. of encoding of their own self-reproduction). The appearance of reflective arrows is non-deducible from the initial structure of the set of catalysts and catalyzed reactions. On the biological level it corresponds to the arising of a hypercycle, i.e. of an elementary biological reflective system. It appears as a realization of a certain possibility which cannot be deduced from the previous organization.

Hypercyclic structure comes into being when the subset of a substrate set of the catalytic system happens to be the matrix for generating and reproducing the set of catalysts itself The hypercycle is based on the correspondence between the two sets of polymer molecules according to internal constraints. At a certain stage of evolution this correspondence causes the appearance of the genetic code which leads to the relative autonomy of matrices from the whole system: they may attain the 'selfish' properties which are realized in the evolutionary process.

Non-computable events, arising through the appearance of reflective properties, generate a system which realizes computation, and so we face 'doing mathematics by real world systems' (Kampis, 1996). A recursive procedure (information transfer) is possible when reflective arrows appear in the formal system which allows a system to realize its self-reproduction. Self-reproduction of catalysts is represented as a 'calculating procedure' according to the program (information transfer) which can be explained in terms of the biomolecular computing paradigm (Liberman and Minina, 1996). In this procedure we need to take into account the influence of the measurement process on the detector itself. That is, recursive calculating procedures imply the influence of calculation on the events of real world.

Any sufficiently powerful consistent logical system is incomplete. According to the Gödel incompleteness theorem, it has true statements expressed by the language inherent to this system which cannot be proved within its frames. This can be interpreted as saying that the foundation of these true statements exists outside of the formal language of the system—being nevertheless an essential feature of it as a whole entity. In other words, a whole system possesses certain characteristics non-deducible from its formal language, and non-reducible to it. In the proof of his theorem, Gödel undertook the reflection (or 'translation') of metamathematical statements about the formal system into the system itself. Owing to this, certain elements of the formal system attained the properties of the reflection of a whole system via the encoding of metamathematical statements.

Such a procedure for generating of reflective arrows is called Gödel numbering. Arithmetization of the system via Gödel numbering leads to the fact that the previously non-formalized basic relations and operations within the system are converted into relations and operations having simple algorithmic nature. As a result, a program appears which can be used for the construction of a model of the system as an interpretation in the formalized language. In biological systems, encoding represents an internal property of a whole system: the code is a consequence of a reflection of the entity (living system) into the finite set of its molecular structures.

2. Logic of irreversibility

Observation and mapping corresponding to realization of information occur with finite velocity, and this is connected with temporal evolution of the system. The act of recognition (based on quantum non-demolition measurement) involves a low-energy interaction between a component of a nonlinear system macromolecular device) and an

environmental input signal that causes the component to undergo a state transition (Barham, 1990). Time irreversibility appears as a consequence of sequential measurements at the stages of information enumerating all sequences of outcomes (Dicke, 1989).

A self-referential process is realized with finite velocity, and this ends up a self-contradiction in reflective systems (Gunji, 1994). Time is an engine which introduces paradox into the real world, and an evolving system realizes a proof of incompleteness for the system to describe time evolution under finite velocity of observation propagation. Contradictory statements become separated by a time interval. This also corresponds to the impossibility of continuous measurements: measurement is realized in finite times (the quantum Zeno paradox).

According to Gunji (1994, 1995), the finite velocity of observation propagation causes the non-programmable infinite regression of a system. It can be expressed in topoic logic, in terms of Lawvere's theorem, as a fixed point. Finite velocity causes unprogrammability, and the fixed point is a fixation of contradictory statements separated by a time interval. This idea relates to the 'causal mechanics' of Kozyrev (1991) who considered the transition from the cause to its result as a basic event on which the conceptual basis of mechanics can be built. According to Kozyrev, the transition from the cause to the result, being an initial irreversible process, is realized as a jump through the 'empty' (i.e. imaginary) point. This can be actually compared with the quantum theory of measurement in which the reflection to real numbers is realized.

The speed of transition from the cause to its result, according to Kozyrev, is described by a pseudoscalar and could be connected with the finite velocity of a 'jump' through the 'empty' point. It may correspond to the time interval of relaxation of a measuring device. Finite velocity of observation propagation via infinite regression forms dissymmetric spatial structures realized in biological organization from submolecular to its higher levels. Kozyrev outlined the approach explaining the connection between time irreversibility and spatial dissymmetry. In this respect coherent percolating events corresponding to the self-assembly mode of computing (Conrad, 1995) may be regarded as a consequence of optimal timing of observation propagation, which triggers resonance effects and self-assembly phenomena and leads to the formation of spatially dissymmetric structures.

Transition from the set of possible states to the description of the real world corresponds to the irreversible process of reduction of potentialities which is described by a reflection from the set of complex variables to real numbers (Rosen, 1977). The idea that the transition from the set of possible states to real ones is described as the transition from imaginary to real numbers occurs to Florensky (1991), who suggested that imaginary points in the time-space continuum serve to glue together of the separate points of the universe into the whole entity. For the 'imaginariness' which expresses a wholeness (for its referential object the place in real existence cannot be determined), the finite formula, i.e. the object expressed by real numbers, can be put into the symbolic signifying correspondence. The latter is a sign by means of which the unavoidable difference between finite and infinite sets is abolished. Signification in this connection is proposed to be a result of a transfinite over-logical action, in which a relation between finite and infinite sets, i.e. between a wholeness and its model, is established.

In the model of the universe suggested by Hawking (1988), imaginary time is introduced in which the universe is represented as a closed holistic structure without frames. After the transition to the real time the reduction to the model in which the 'beginning' of the universe and its inflation appear. The most developed the idea of reduction of potentialities described as a reflection from complex to real numbers is present in the quantum mechanical formalism. The complex Ψ-function of the Schrödinger equation is reduced during measurement into the set of real numbers.

According to El Naschie (1995), complex time gives a consistent description of phenomena and physics of time past and time to come while present time is given as the modulus of this complex quantity (as a reduction to real numbers). Complex time clarifies effects arising from the

Einstein–Podolsky–Rosen (EPR) paradox which realize non-local instantaneous correlations between particles appearing in EPR-like experiments. Non-locality effects are a part of quantum percolation events provided via electronic–conformational interactions and representing a vertical self-assembly mode of computing (Conrad, 1996).

3. Realization of information and coherent events

Encoding cannot predetermine the system's structure in such a way that the structure itself is described pre-formationally within the coding systems. By means of the determination of the structure of enzymes, the processes which determine transformations via actualization of definite programmable initial states are encoded. The encoding phenomenon leads to the realization of processes which constitute the trajectory of changing interactions which, being realized in definite conditions, lead to the appearance of concrete spatial structure. Therefore, there is no isomorphism between the code and the morphology of the system.

Interactions between the realizations of separate programs constituting a complex genomic system lead to the generation of vertical coherent events. What is the basis of interaction between different realizations? On the quantum mechanical level it is a coherence via synchronization of phases of the wave functions between different components possessing non-local and non-force character. Coherent states actually bridge the gap between micro- and macroscales, and the dynamics of enzymes and high-order structures is explained by coherent phenomena (Fröhlich, 1983). A coherent state is limited by the minimum uncertainty condition (Li, 1995), and even atomic structures can only be formed within the coherence volume. Quantum mechanically, Planck's constant determines the condition of the smallest possible time interval that is necessary to transfer the energy of a wave to the ideal detector system (Popp, 1995), and real times of measurement form concrete patterns of interactions leading to the realization of coherent events and formation of spatial structures. Dicke (1954) showed that the ordinary imaging of spontaneous re-emission of light from optically dense media (i.e. interference patterns) becomes completely changed as soon as mutual distances of absorbing molecular antennae get much smaller than the wavelength of light. These events are based on multiple propagation and diffraction, and can significantly improve the degree of coherence of light.

Coherent percolating events form invariants which are preserved during topological reconstructions of a system. Transformation of molecular texts of DNA and RNA using molecular addresses (splicing, horizontal gene transfer, etc.) is an important event which could be described as a 'logical coherence' in frames of topoic logic. It can give a background for the establishing of invariants of information processing (of transformation of molecular texts). This will explain developmental and morphogenetic processes and evolutionary transformations, including horizontal transfer and directed mutations, etc.

A topos is defined as a space with variable topology. Fixation of contradictory statements within the topos is possible by means of its intrinsic logic. Lawvere's theorem of fixed point introduces this fixation: it implies that self-definability cannot be proved logically, it means incompleteness (Gunji, 1995). When we introduce time, which separates contradictory statements, we sink from the mathematical into the physical world and face infinite regression avoiding simultaneous existence of opposite definitions.

For development, self-reproduction and overcoming the tendency to self-degradation, the complex system should be a part of a larger system in which it is included and it should generate reflective arrows (Gödel numbers) (Von Neumann, 1966). The reproducing configurations of biological systems are at a level that defines identity of these systems. This construction means the establishment of a configuration with a description which cannot be given in advance, for the reason that it is being defined just in this process. Thus, statements of our metalanguage that reflect the ways configurations change cannot be given independently from the configurations themselves (Kampis and Csànyi, 1987). The procedure of

attaining these configurations is therefore a language game which rules are established during the process of realization of configurations.

4. Genericity, information and growing of complexity

The appearance of new encoding systems corresponds to a construction of new formulae (new Gödel numbers), and for this it is necessary to go out from the frames of the existing formal system, i.e. to realize 'a metatheoretic jump' for encoding of a new possible organization. This jump cannot evolve in a single way from the structure of existing formal system. The increase of 'informational content' is non-algorithmic, and interaction between individually computational systems non-computably generates emergent phenomenon (Kampis, 1996). Therefore, the truth of a new formula cannot be proved by finite means.

Newly generated structure is put into correspondence not to the previously existing reality, but to the changed reality non-recursively modified after the inclusion of this structure in it. The evolved system realizes the reflection to the area which is not defined before. Irreversibility of transformations can be explained by its logical foundations. It is determined by the fact that a Gödel number which is non-deducible from the structure of formal system cannot be obtained by reversible logical operations. Transformation therefore is analogous to the creation of new formulae (Gödel numbers), which were absent in the initial formalized calculus. An active combinatorial processes of self-modification of information transformation via molecular addresses), being an internalized language game, allows a system to generate wider possibilities for creating Gödel numbers. The new solution appearing during the evolution of a formal system cannot be obtained in a recursive combinatorial way. Therefore, evolution cannot be predicted with certainty, it can be only prognosticated with more or less exactness. The uncertainty principle is its physical background (Matsuno, 1992).

A language game without rules can be fixed (internalized) within a system and represents a concrete dynamics of transformation of genetic material according to molecular addresses. Finite time of observation propagation, i.e. of realization of information, is an important part of competition between programs: they may differ in their intrinsic times of realization, and this leads to the specific development of a dynamic process. During this process coherent events corresponding to realization of interacting individual programs form a percolating network, and this leads to a concrete spatial (morphogenetic) pattern. This pattern should correspond to the condition of optimality, i.e. should be constructed using an optimal coordinate scale which is built mostly by non-local transfer (percolating coherent events, fluctuons, mobile proton states, etc.). Coordinate scale is a manifestation of dynamics which generates different forms in different coordinate systems (Thompson d'Arcy, 1917). Quantum theoretically, coherence means that one minimizes the uncertainty product (Popp, 1995), i.e. its basic conditions give rise to the minimal price of action during measurement and calculation. The principles of development of coordinate scales governing morphogenesis are crucial for understanding form generation (Marijuan, 1996).

Elements of formal systems which were present previously can attain different, new values, establishing a new level of system organization. Therefore, the appearance of new evolutionary organization is an action which cannot be described by finite means. Its logical basis is an incompleteness of the formal system, which allows it to ascribe arbitrary values to the statements which cannot be proved in the frames of this system. Combinations of elements carrying information do not exclude concrete rules (in the frames of Wittgensteinian language game) that limit and define evolutionary processes and morphogenetic transformations.

5. Conclusion

The phenomenon of actualization corresponds to a reflection from the infinite set of potentialities into a finite set of actualized elements in the frames of the self-referential process. For its de-

scription only spatial relations are insufficient: the irreversible time flow separates the references to the whole (the set of potentialities) representing a biosystem and to its finite actualized model. A self-referential process occurs with finite velocity, and contradictory statements about the whole and its elements become separated by time interval.

The operation of quantum reduction of wave function realized in biosystems by macromolecular devices is a background of the actual irreversibility and time flow. The duration of the measurement process, in which the collapse of wave function takes place, determines the degree of non-demolition and predictability of its result, being a necessary precondition of quantum computation and information transfer. In the whole system non-demolition and non-locality are maintained by percolating coherent events which generate patterns for the formation of spatial structures.

Generation of information network is realized via the emergence of a subset of reflective arrows within the set of mappings (logical elements) formed by quantum reductions and representing as Gödel numbers. The Gödel numbering corresponds to the appearance of a hypercyclic structure with the encoding within it where previously non-formalized relations are converted into the relations having an algorithmic nature. As a result, the information network is developed that actually 'holds' the potential possibilities of the whole system and allows it to function according to its internal recursive constraints. The active combinatorial process of self-modification of information, being an internalized language game, preconditions evolution of the system and growing of complexity.

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