Computability and Insolvability of Simulation Processes for Anticipatory Behaviour in Evolutionary Systems

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Abstract

A biophysically tenable description based on the present understanding of evolutionary systems is discussed, which relies on a hierarchical dynamical approach to an evolutionary chain of *increasing abstraction* levels through compression of information by *n*-dimensional attractors of chaotic dynamics. The capability of simulating the environment and other evolutionary systems through anticipatory behaviour so attained cannot be described fully through Thermodynamics, while the so-called "*Great Puzzle of Theoretical Biology*" could be solved through a quantum physical approach. Computability and insolvability problems would be overcome through an *energy-free* geometrized and topological approach stemming from an analysis of relationships between the *logical space* and the *phase space* of an evolutionary system.

Keywords: nanobiology, chaotic dynamics, quantum life, topology, geometry

1. Introduction

The correction to Darwin's fully random selection concept of evolution was introduced in 2000 [1], according to which genome changes would not be just random, as the genome itself would have an inner activity capable of some control on the environment. So the corrected Darwinian evolution is now said to *favour the prepared genome*. The biochemical and genetic experimental results [1] leading to the concept of *"molecular anticipatory strategies"* can be interpreted theoretically as mechanisms stemming from the physics of the intracellular medium, mainly the cytoplasm, as a nonlinear self-organizing active environment providing *positive* molecular friction, e.g. first by storing a part of its energy input as potential energy (*conformational modes* of complex macromolecules and supra-molecular structures) or as kinetic energy (*lattice oscillations*), and then releasing it as nanoscale-level *active* friction to an *"activated (system + reservoir) transition state"*. Moreover, interacting Heisenberg's electron and photon fields should be added to Heisenberg's molecular field to describe the microphysics of self-organized charge transfer processes, of primary importance in biological processes, embodying coded interactions from unitary and non-unitary events which show in the macroscopic level processes of the living being because they strongly lower the activation entropy and then the activation energy of such processes. Such

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classical and quantum mechanisms would be variable in their nanoscale and/or microscopic details from system to system; how could their global behaviour as shared by what we call "*evolutionary systems*" be described? What about the logical and physical built-in source of anticipatory behaviour winning over pure randomness?

Logic and physics should be taken jointly in modelling evolution, as biosystems are essentially information-driven, not energy-driven systems, according to macroscopic biophysics. Accordingly, the model developed here will feature a close correspondence between the molecular level logical space and the molecular level (physical) phase space of the system. It will be shown that a Quantum Field Theoretical approach to biosystems might solve the so-called "*Great Puzzle of Theoretical Biology*", i.e. the fact, inexplicable by classical physics, that though dynamic ordering processes occur within a biosystem, the same features a dissipative character, i.e. the input energy flow equals the output energy flow. It will be shown that such molecular level logic – *involving self-organization and cognition* – might ask for topological approaches for describing hierarchical dynamical informational chains, and that it would take us to think of life as a phenomenon of cosmological nature.

1.1 Some Definitions and Concept for the Logical-Physical Approach to Evolution

This paper is an attempt at giving a theoretical interpretation of the experimental results in molecular level biological evolution mentioned above [1] which show clearly that a kind of molecular level anticipatory behaviour occurs. Moreover, as far as I know, the mentioned experiments plus the following theoretical interpretation are at the present time the only concretely physical results that allow an anticipatory behaviour at the biomolecular level to be recognized. Thus, some terminology is to be set forth to proceed with clearness and distinction to stress the biophysical roots of anticipation.

Evolutionary chain: the **holistically connected** set of increased abstraction levels making up a physically tenable model of an evolutionary system, i.e. a system which according to the well known principles of thermodynamics is *open*, *far from equilibrium*, *self-organizing*, *cognitive*, and *self-reproducing*.

Kinetic level: as is well discussed in any textbook on statistical mechanics, this is the level in a system that asks for a fully kinetic description as to the distribution of speeds of the elementary components, and is then followed by the **hydrodynamic level** where such speeds have undergone an ordering in a particular direction.

Logical space: the abstract space in which the phase space conditions and occurrences take the aspects of logical operations, i.e. a logical meaning. Stated otherwise, the space of the *isomorphisms* between phase space occurrences and their logical purport.

Kinetic level logic: accordingly, this is the set of logical operations which are isomorphic with the kinetic level occurrences in the phase space.

Codes and **codes of codes**: according to the standard meaning of a code, obviously in the chain of increased abstractions both elementary codes and upper-rank codes that code for sets of elementary codes are formed. They are formed physically by inseparable chains of nonlinear differential equations as will be discussed in the following. The hierarchy of abstraction levels is just a hierarchy of **codes of codes**.

Abstraction *level*: *level* featuring a certain **compression of degrees of freedom.** While this term is analogous to the term used in computer science as to the languages to go from the "*machine language*" to increasingly upper languages for the man-machine dialogues or so called "*computer programming*", there is a deep difference between the two terms. In this text, reference is made not to logical relationships but to physical degrees of freedom.

Hardware and **software**: as applied to evolutionary systems, such terms stand for the structural parts and the functional parts respectively for the *structure-function* solidarity of evolutionary systems. In the literature the latter as a holistic agency is termed "**wetware**", with reference to the biological watery cytoplasmic environment in which the biological structures work.

Cognitive system: in this paper, this is a term designing a system in which any *structure-function* holistic level in the evolutionary chain can read the codes in the level immediately below it. Cognition in this sense is a necessary feature for a system to be evolutionary and, according to the new experimental findings, anticipatory. Any other speculative meaning concerning the so-called "*problem of consciousness*" of philosophical nature is absolutely excluded from the present treatment of evolutionary systems. Maybe a fully physical notion of consciousness could be grasped by also considering memory and the degree (as complexity and numerousness) of syntactic/semantic networks leading through evolution from the molecular level cognition (the intelligence of cells) to the macroscopic organs level (the intelligence of the developed being as a *sensing – information processing – actuating system*).

2. A Far-from-Equilibrium Thermodynamic Approach to Logic and Physics

The openness and far-from-equilibrium conditions lend themselves to highly nonlinear chaotic dynamics, conservative as well as dissipative. But also non-chaotic nonlinear dynamics can occur and it is interesting for self-organization because of its capabilities for autonomously building long-range spatiotemporal dynamic structures from disorder. However, self-organization does not mean cognition, if we define the latter as the capability of a system of describing itself. Stated otherwise, an evolutionary chain could not come from just self-organizing levels of the chain itself. Indeed, a system can be self-organizing without "*being aware*" of its capability, as clearly occurs in some well known spatiotemporally self-organizing chemical reaction-diffusion systems. Cognition thus implies the capability of the hardware of an upper-rank level in the hierarchical chain to read the software of the level of the immediately lower-rank level. No evolutionary chain made up of just self-organization processes would be possible. Cognition is necessary as the physical basis of ***anticipation through simulation***, as will be discussed in the following.

The thermodynamic, or hydrodynamic, or kinetic level logic, with consequent simulation and anticipatory behaviour, come just from the following considerations.

Information compression of various dimensionalities are realized through such dynamics: 1) steady states, of dimensionality zero; 2) limit cycles, of dimensionality one; 3) strange attractors with high dimensionality with sets of positive Lyapunov exponents λ_+ **and** sets of negative Lyapunov exponents λ_-. Now, attractors 1) and 2) are good as information compressors, and attractors 3) feature a very complex dynamics, extremely sensitive to changes in the control parameters and initial conditions. They cause trajectories in phase space to expand (λ_+) so producing entropy on one side and to converge (λ_-) on the other side so producing information, with

$$\Sigma/\lambda_-/\geq\Sigma/\lambda_+/ \qquad (1)$$

as a relationship that holds true *on the average*. The essential logical and physical point for simulation and generation of *anticipatory mechanisms* is that a very large number of environmental stimuli in the form of N-term time series is thus mapped into a set of few chaotic attractors of *dimension* $<< N$, i.e. it is compressed into minimal length algorithms. This means that the construction of codes is not a copying process but a simulation of what can be generally designated as the environment. And this is the way of communication between evolutionary systems, as intra- and inter-level attempts at breaking the code of the partner. A *hierarchy of codes* resulting from a similar coding of codes is formed, leading to the self-organized upper-rank codes that control the so called higher functions. New information, i.e. information not present in the initial conditions, is generated in the physical and logical space by contraction of the phase space volume, i.e. contraction onto an attractor of dimension lower than the original space. The sum

$$\Sigma/\lambda_-/+\Sigma/\lambda_+/ \qquad (2)$$

gives the average volume contraction rate. It is interesting to remark that a pattern of subtle processes in the logical space on the molecular level comes from the dynamic interplay in phase space of unpredictability, reliability, instabilities, bifurcations, broken symmetries, multiplicity of solutions and exponential divergence. A nanolevel memory also participates in this physical interplay making up the *logic in the eyes of molecules*: indeed, nanochaotic strange attractors are good *dynamical* memories due to their high information dimensionality. Within this memory the continuous *aperiodic flow* within the attractor gives rise to information production: the system can learn from its own memory. But when would this flow begin with causal disconnection and exploring the phase space for simulation, through coded interactions, the environment or other evolutionary systems for self-organizing into an anticipatory dynamics? This point will be tackled in **Section 3**.

Thus the parameter that can fully characterize the logic and physics of the evolutionary system is λ, with λ_- or $\lambda < 0$ as an information sink, λ_+ or $\lambda > 0$ as a source of information, and $\lambda = 0$ as no production and no dissipation of information. The basic set of correspondences between a logic space and a phase space, whose roots are in the present considerations, were set forth in [2].

It is worth elucidating the concepts of information sink and source. Both terms mean essentially a change of knowledge. But by *sink* it is to be meant the exertion of a constraining action by the dynamic flow on knowledge, so that information is revealed if our question is a prospective one (a value constrained in a smaller interval corresponds to increase in information) or is lost (dissipated in the thermodynamic sense) in case of retrospective question (a value within a larger interval is a decrease in information), and thus the sink is a source of negentropy, if the flow is thermodynamic; By source it is to be meant a *creation action exerted through expansion*, i.e. an action that is a loss of information from the prospective standpoint (uncertainties in a starting range increase in an expanded interval) but is an information increase according to a retrospective standpoint (uncertainties decrease within a smaller interval). A feedforward and feedback information flow – in this nonlinear conservative **and** dissipative dynamics – does set forth autonomously which nanoscale physics can be put in correspondence with the logic of steps making up the logic behaviour. *Codes and codes of codes* through increasing N-dimensional compression make up a chain of increasing abstractions – *reduction of degrees of freedom* – featuring the problems discussed in **Section 3**.

3. The Logical Conundrum

... further advances in Artificial Intelligence can be achieved
only through the development of a unified theory of physics and logic.
Stern, A., 1992

While referring to Artificial Intelligence and any nanostructured intelligent robot [3], this quotation would fit quite well both biological intelligence and any biosystem. Even the subcellular members can be considered as smart systems.

Anticipatory features, giving rise to new information, must come through far-from-equilibrium dissipative and highly nonlinear dynamics. Strange attractors with high numbers of degrees of freedom, i.e. many values of λ, can be investigated by means of Kolmogorov-Sinai entropy that can supply the value of the upper limit of the average amount of information not contained in the initial conditions that is gained per second.

Indeed, with S as the entropy, $< I >$ as the information change per iteration of an orbit in phase space, P as the asymptotic probability distribution of an orbit at the same value of a given general parameter, P_n as the values of successive iterations of the initial probability density, S_N as the entropy after N units of time as the system evolves, τ as the unit time interval between samples of a time series, and L as the side of a cell in phase space, we would have for the time t_f necessary for the attractor to get causally disconnected

$$t_f = S / < dI/dt >$$

$$= [\textit{entropy as a priori uncertainty about the initial point as from the distribution } P_0] / < [\textit{information production rate as bits per second}] >$$

with

$$S = \int P_0(x) \log [P_0(x) / P(x)] dx$$

expressed in bits.

After time t_f information would no longer be revealed through removal of uncertainties in the initial conditions, but the system would generate new information as a result of its own flow evolving in state space. This comes from the exponentially diverging rate of nearby trajectories in phase space, the microscopic noise originating from a much shorter time scale level becoming amplified instead of being washed out. The **Kolmogorov-Sinai** entropy supplies the value of the upper limit K of the average amount of information not contained in the initial conditions that is gained per second:

$$K = \lim_{\tau \to 0} \lim_{L \to 0} \lim_{N \to \infty} [1/N\tau] [S_N - S_0]$$

But this dynamics and the interplay between unpredictability, reliability, instabilities, bifurcations, broken symmetries, multiplicity of solutions and exponential divergence within *past memories* congealed in the high λ's attractor, while being what could be described as the basis for the *"well prepared"* anticipatory system – the well prepared genome of ref. [1] – might give rise to inter-level communication problems as a result of

1. t_f of the lower level being shorter than that of the upper-rank level, as in the convolution dynamic signals from the lower level would be taken to be noise
2. relaxation times of the two levels being very different; this would mean very different energies of the two dynamic processes, and the convolution dynamics could result in non-computability as to the description of the system on the basis of energy, or in insolvability in the logic space

In Section 5 the overcoming of problems as in point 2 will be discussed. However, this evolutionary chain through anticipation from simulation, while featuring no uppermost abstraction level, would be undecidable as to the possibility of the existence of a minimum abstraction level as a result of Gödel incompleteness theorems.

4. Does Quantum Physics Offer a Loophole out of *"The Great Puzzle"*?

Thus t_f would be the time when a *"prepared genome"*, bearing a memory where past experiences had been congealed into an inside dynamics with many λ*'s* for rich exploration behaviour, would start looking for simulation and anticipation through logical (conservative) and extralogical (conservative or dissipative) dynamics. But where do so many λ*'s* come from? And how the connection between the nanoscale dynamics, possibly involving a substantial microphysical contribution, and the macroscale could be described?

Flexibility of macromolecular and supramolecular biological systems can supply the high number of degrees of freedom for the whole nanostructured hierarchical system to support itself and even evolve against the degrading action of noise. Indeed, flexibility of the system causes redundancy R to increase as a result of the fact that the maximum entropy S_{max} corresponding to the maximum number of Planckian complexions at equilibrium grows faster than entropy $S(t)$ at any time:

$$R = 1 - [S(t)/S_{max}]$$

with $dS(t) = /dS_e(t)/ + /dS_i(t)/$ increasing with time due to increase in number of degrees of freedom from flexibility, where $dS_e(t)$ and $dS_i(t)$ respectively are the entropy associated with the matter/energy exchange with the environment in the open system and the entropy produced inside the hierarchy.

The task of identifying the set of relevant variables to get the suitable distribution function in the state space or the set of observables to get the suitable density operator for the possible quantum system involved at the nanolevel is a very hard one. This is because of the following reasons:

1. the principle of microscopic reversibility of linear non-equilibrium thermodynamics cannot be applied, as the averages of the coarse-grained variables do not obey linear first order differential equations any longer, so that on going to the macroscopic levels the equations (stemming from a master equation) describing the collective properties of the nanoscale dynamics are nonlinear
2. as a consequence, the levels of description – the *logic processes in the eyes of molecules* – cannot be decoupled

The macroscopic – thermodynamic or hydrodynamic or kinetic – level, ordered in space (compartment formation, stable structures, tissues) and in time (series of reaction-diffusion processes etc.) would be closely connected to the microphysical, i.e. quantum, world. Accordingly, the strong indication from the "*Great Puzzle*" of the quantum world supporting the whole biosystem and making the same a macroscopic quantum system would be a strong indication that it is the microphysical world that *informationally, not energetically*, fuels the nanoscale (mesoscopic) and the macroscale levels of the anticipatory evolutionary system.

Due to the *"extended"* [4], open and thermal nature of biosystems, a Thermal Quantum Field Theoretic (**TQFT**) approach should be followed in tackling the problem of grasping the ordering power of the biosystem with no energy loss. Indeed, this fact inexplicable in classical physics could be solved in a **TQFT** approach, as ordering in that case might be generated as a result of condensation of collective modes (a typically quantum process) of *massless* modes, so that no contribution would be given to the ground state energy. Moreover, it is the spontaneous symmetry breaking that generates order, so that order generation through this self-organization through simulation and anticipation is autonomous, not supplied from the outside. Thus the problem seems to be that of finding a solution to the task mentioned just above of connecting the two worlds, the microphysical world giving at time t_f the kickoff.

5. Geometrizing the Approach

So the dynamic or energy approach could lead to incomputable computing and unsolvable logic. Moreover, the **TQFT** approach shows the fundamental character of biosystems to be *information-driven*, not energy-driven, and basically arising from spontaneous symmetry breaking. Accordingly, an energy-free approach through geometrization of the problems concerning hierarchical dynamical levels with high inter-level energy gaps, which are likely to be incomputable. Geometry and Topology would supply representations of the problem in which both quantity and quality would be taken into consideration. This would be a really complete scientific approach because modern science is not the success of the thought category of *quantity*, which is quite a widespread misconception, but the success of the category of *quantifiable qualities*. The discipline of geometric quantization [5], mainly through the Heisenberg group, would lead to integrated, i.e. *holistic*, views of biosystem hierarchical dynamical levels, that would be difficult to describe through a dynamic approach. Accordingly, all that seems to lead to the application of finite temperature quantum field theory, an approach for which the reader interested can find an optimal introduction in the references [6 - 9]. A reasoned application of those principles which is suitable for the uninitiated can be found in [4].

The very physical gist of such approach to the seemingly eternal question "what is life?" consists in the fact that a field theoretic approach instead of the atomistic, "*molecular based*" approach can put into evidence the global properties of large *quantized molecular ensembles*. This transition through a multi-body approach would mean a transition from the *"number crunching"* philosophy of syntactic (logic) computers to geometrical and topological computing that might include semantics. In a search for any essentially quantum nature of biological physical information, the molecular notion of the gene as well as the kinetic quantum physics that supplies the tools for dealing with dissipative nanostructures, would just return descriptions based on *single-particle dynamics* interpretations, as is the feature of Quantum Mechanics. They would be properly employed for investigating nanoscale, molecular-based quantum kinetics and/or dynamics of reactions or of reaction-diffusion mechanisms in biological systems. Instead, a **quantum field theoretic approach** will allow a *quantized* *multiparticle state* description to be achieved for the *matter-energy-information* system in question through proper choice of the fields. **QFT** [8] refers to 0 K temperature; so a proper approach would be based on Thermal Field Theory [6, 7, 9] for the case of a finite temperature.

6. Conclusion and Outlook

Self-organization as a result of simulation and anticipation through the dynamic processes, classical and quantum, in evolutionary systems whose description has been proposed above, appears to result in a solidarity of inseparable unity of structure and function, from the quantum to the macroscopic levels, through a complex information-revealing dynamics made possible through *cognition* as a "*glue*" spread along the whole evolutionary chain and taken to consist in the capability of an upper-rank level hardware to read the software of the immediately lower-rank level in the hierarchy. These unitary aspects are definitely lost in the usual energy-based description, which rests on the principle of analyzing the biosystem into parts, so altering or losing its unitary aspects, one of which is the longed for *physical grasp* of the vague, philosophical-minded notion of *consciousness*, and so also meeting possibly with non-computability and insolvability. Consciousness might be shown to be a property emerging from the mentioned quantized many-body view attained by the **TQFT** approach. *Group theoretic* approaches with the algebras as relative could be a valid tool for overcoming this kind of *microanatomy complementarity*: either structure or function can be described, the deepening of one causing the loss of the other. Group theory indeed, based on symmetry considerations, would be fit for a description of biosystems as informational systems fuelled by spontaneous *symmetry breaking* as the source of their basic *order parameter* at the quantum level.

Such views would be certainly improved and furthered if this *biology seen through theoretical physical glasses* would be more widely readable for biologists. Maybe teams made up of biologists from the various fields of this discipline and physicists from the communities devoted to nanochaos, nonlinear dynamics and field theories might shed more light on the mysteries of life and might overcome felicitously the way of thinking expressed some years ago, in an indeed enjoyable flash of wit, by the clever biologist Sydney Brenner in his "*Loose ends*" columns in the journal "*Current Biology*", with reference to something dealing with biology like the present paper:

The trouble with theoretical physicists is that they produce theories so deep as to have lost touch with reality. I hope this one is so deep that it sinks without trace.

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