

## **Biological evolution — a semiotically constrained growth of complexity**

*Abir U. Igamberdiev*

Risø National Laboratory, Plant Research Department,  
P.O. Box 49, 4000 Roskilde, Denmark  
e-mail: a\_igamberdiev@hotmail.com

**Abstract.** Any living system possesses internal embedded description and exists as a superposition of different potential realisations, which are reduced in interaction with the environment. This reduction cannot be recursively deduced from the state in time present, it includes unpredictable choice and needs to be modelled also from the state in time future. Such non-recursive establishment of emerging configuration, after its memorisation via formation of reflective loop (sign-creating activity), becomes the inherited recursive action. It leads to increase of complexity of the embedded description, which constitutes the rules of generative grammar defining possible directions of open evolutionary process. The states in time future can be estimated from the point of their perfection, which represents the final cause in the Aristotelian sense and may possess a selective advantage. The limits of unfolding of the reflective process, such as the golden ratio and the golden wurf are considered as the canons of perfection established in the evolutionary process.

### **Semiotic causation of evolution**

The living process is self-referential: living system in its development and reaction to external stimuli makes an internal choice by reducing indeterminacy of the potential field in interaction with the environment (Igamberdiev 1992, 1993). In other words, the system measures itself as embedded into the recognised part of the environment, the Umwelt. This reflective action is based on the semiotic structure of living system, which includes the inherited description with rigid

grammar and flexible combinatorial rearrangements generating possibilities of internal choice. The inherited description itself can evolve towards incorporation of environmental inputs as recognised (i.e. signified) by the system. Thus evolution of biological systems is semiotically constrained (*'semiokinesis'*) (Igamberdiev 2001): it includes the recognition and signification of external stimuli within the internal structure of biosystem. Recognition and adequate reacting on external inputs will be a final cause of evolution, the point of attraction for evolutionary movement of the system.

According to Aristotle, any movement is constrained by four causes. The material cause corresponds to an uncertain potential field from which the system evolves (the timeless matter). The formal cause is the structure of the system inherited from the time past. The efficient cause will represent non-equilibrium input to the system, an action in the time present. The final cause is the state in time future to which the movement is attracted. Such subdivision of causes is an intrinsic property of the description of the temporal appearance of spatial objects. The final cause will represent an optimal state of biosystem in a given environment, changed by inclusion of modified system into it, with the maximal fitness. It will mean an observability of environmental inputs as a possibility to recognise them (via adequate reacting on them, i.e. imprinting and encoding). Evolution moves towards incorporation of all potentially being observable and this corresponds to the process of adaptation via complication of organisation of living systems.

The self-referential living system originates as divided into phenotype (dynamical image) and genotype (embedded set of symbols). External influences are non-digitally recognised (imprinted) by the metabolic system of phenotype. The digital genetic information forms an internal programmable structure of biosystem. The encoding digital system is not static — it exists as a set of possible superpositions. Thus living system possesses the trinary semiotic structure including (a) the metabolic network based on specific recognitions (imprints), (b) the genome as a signifying embedding within the metabolic network, and (c) the superposition of genome rearrangements as a potential whole of the system.

The evolutionary increase of complexity becomes possible when the genotype appears as a system distinct from the phenotype and embedded into it, which separates energy-degenerate rate-independent

genetic symbols from the rate-dependent dynamics of construction that they control (Pattee 2001). The flexibility of genetic system is based on induction/repression of genes and on combinatorial rearrangements of the genetic material. What is not recognised at time present (outside the limits of metabolic and genomic flexibility) may be evolutionary incorporated when new structures arise (new reflective configurations are established) and the non-observable transforms into the observable. This corresponds to a metasystem transition (Turchin 1977; Sharov 1999) being possible if the system is redundant (both in the phenotype, which gives rise to new metabolic pathways under the efficient cause — and in the genotype, which memorises this).

Self-reproducing systems have to contain complete descriptions of themselves (Neumann 1966). According to Kolmogorov (1965), the complexity of an object (system)  $s$  is a minimal length of a program  $p$  for the universal Turing machine  $T$  that would print out a detailed description of this object. Increasing this length for the digital internal description of living system will correspond to an increase of its complexity. A newly generated structure being defined just in the process of its establishment cannot be computed from the state existing at time present/past. It therefore cannot be recursively deduced from the previous state and therefore evolution cannot be predicted unambiguously. But it could be forecasted from the time future, i.e. from the most optimal configuration that could be achieved in the concrete context situation. This optimal configuration will represent an Aristotelian final cause for the evolutionary process. The process of movement will be attracted to this point (or the set of points in a general case).

### **Heredity as a memory**

Biological system is able to recognise certain environmental inputs and incorporate their images into its internal structure (Barham 1990). The flexibility of metabolic system means that it responds to changing environment by redistribution of fluxes within it, e.g., the externally caused excess of metabolite  $A$  triggers the emergence of reaction for which  $A$  is a substrate (Kampis 1996). Memorisation of this redistribution will occur in the genetic system, e.g., via specialisation of

different isoenzymes specifically catalysing appearing metabolic fluxes (Igamberdiev 1999a). This will lead to the growth of complexity of the genetic system. Thus living organisms as self-modifying systems utilise (via memorisation) these persistent shifts in their defining interactions and variable composition (Kampis 1996).

Memorisation of the changes in metabolic systems provides new broader limits of adaptation. It occurs via the formation of self-reflective loops, i.e. mappings between the newly appeared feature and certain genetic elements. The latter will acquire a property to reflect it (via combinatorial events) after which the non-recursive process becomes recursive. In accordance with the Baldwin effect, the changes in the organism precede the changes in the hereditary system that fixes them (Baldwin 1896). This corresponds to the Baerian theory of evolution (Baer 1864; Kull 1999). The process of adaptation via recognition (semiotic fixation) of new environmental inputs means that living systems themselves form their adaptive niches in the course of evolutionary process of increasing their complexity. Since the connection of the *signifiant* and *signifié* is arbitrary, the formation of new structures appears as a casual, we cannot predict (recursively follow) it. In other words, it will be formed via language game — an open process without frames (Wittgenstein 1953).

The language game however has restrictions implied by the structure of genetic system. These restrictions, following Chomsky (1965), we can define as the universal or generative grammar. It will be a computational system restricting the field of non-computable events. In general, grammar is a computational system that mediates a mapping between the *signifiant* and the *signifié*. Chomsky (1965) introduced the concept of preformed linguistic theory denoted as universal grammar, i.e. a system that specifies a form of concrete grammar and provides a strategy for selecting such a concrete grammar. This universal grammar in living systems has high generative capacity and includes constraints of the genetic code, together with constraints of rearrangement of the genomic system such as splicing, sticking and insertion/deletion (Georgescu 1997). These constraints allow obtaining universal computability models (language generating devices equivalent in power with Turing machines) (Paun, Salomaa 1997).

The universal grammar will be a formal cause for concrete grammar generation: combinatorial events will provide a search space for choosing of appropriate grammar. Probably the universal grammar

includes to some extent the mechanism of internal evaluating input sentences, not only in conscious beings but also in all living systems. This will provide deviation from randomness in evolution of semiotic system e.g. in the case of directed mutations. The ways of such evaluation may include some possible selections in the potential field before reduction in the whole system operating as a quantum mechanical observer (Ogryzko 1997). The whole of the system in this approach will correspond to the set of all its potential superpositions. This set will be a semiotic interpretant of the system's adaptive behaviour: by genomic reconstruction the system fits to the acquired change in the set of imprints (metabolic organisation) thus incorporating it. Evolutionary reconstruction of the genome thus interprets the acquired change by memorising it and allowing its use when it is necessary.

### **Formal incorporation of the final cause into the description of biological evolution**

In physics, in frames of the anthropic principle, the final cause means observability, thus a framework is needed to explain observability of the world. The approaches to describe evolution of the system towards observability are based on understanding of quantum measurement (as opposed to the classical measurement of external objects) as a measurement of the environment together with embedded measuring system, which cannot be separated from it. The assimilated part of environment as recognised by the system can be defined as the *Umwelt*. Recognition of new observables during this measurement will generate a simultaneous complication of the measuring system itself and the *Umwelt*, it will correspond to the Gödelian enumeration within sets and lead to the possibility of measurement of a newly formed system plus environment (Igamberdiev 1998, 1999b). Although the measurement itself is not recursive, it will generate enfolded embedding structures viewed as appeared in the continuous recursive embedding process after it takes place. The appearance of a new description means that the system memorises its optimal state in the concrete environment, i.e. it measures not the external environment, but itself plus the environment (itself embedded into the environment). This is the difference of the quantum measurement

from the classical measurement, which views the environment as external: the system views itself as embedded into the Umwelt, the recognised part of environment. It should have a memory as a distinct set (embedded set) which will constrain its movement (as a formal cause). Attraction to the most optimal states (canons) takes place during the recursive embedding. These most optimal states will include fundamental values (constants) inherent for the unfolding process.

For the description of observable world, which consists of the systems perceiving both outer objects and an inner self, an apparatus of the set theory was applied (Bounias, Bonaly 1997a). A special type of sets (closed sets) exists upon intersection of topological spaces owning different dimensions. This intersection will incorporate a contradiction (fixed point) in the description. Fixed points will generate internal choice accounting for the biological self. This description provides theoretical justification for the existence of memory. The closed sets in this approach are similar to the monads of Leibniz (1965) which constitute and observe the Universe. The empty set will correspond to a vacuum that is still not allotted by features (Bounias, Bonaly 1997b). The memory appears as a 'sign-creating activity' (Hegel 1971), linking sets with different dimensions.

A concept with emphasising the fixed point as a central element of the contradictory structure uniting parts and a whole was applied to biological systems by Gunji *et al.* (1996, 1999). Following this approach, an uncertainty in interaction between biosystem and environment is reduced via formation of a self-reflective loop, which leads to establishment of emergent computation such as primitive recursive functions. Time in this approach separates contradictory statements allowing them to appear in a sequential order. In this model, all interactions encompass the notion of detection. The latter can be expressed as a process generating a contradiction. The process of internal choice in the course of adaptation includes inducing a fixed point and addressing a fixed point. It can be compared to indicating an element with indicating a set consisting of elements, that is, to Russel's paradox. Evolution as a formation of reflective loops during measurement is generally relevant to resolving a paradox or a logical jump.

Dubois (1997) introduced a concept of the incursive computation, in the sense that an automaton is computed at the future time  $t+1$  as a

function of its neighbour automata at the present and/or past time steps but also at the future time  $t+1$ . The development of this concept for inclusion of multiple states led to the concept of hyperincursion, which is an incursion when several values can be generated at each time step. The series of incursive and hyperincursive actions will produce fractal patterns defined by functions of the past, the present as well as the future states. External incursive inputs cannot be transformed to a recursion. But they can be internalised and thus transformed to recursive inputs via self-reference (as being memorised in the system as signs). Interference of inputs in fractal generation gives rise to various fractal patterns with different scaling symmetries. These patterns have however some fundamental symmetrical rules at different scales, corresponding to potential existence of certain canons in incursive computation. Hyperincursion means superimposition of states similar to that in quantum computation (Dubois 1998). In incursive and hyperincursive fields (which are viewed as hypersets, i.e. sets including themselves), undecidabilities and contradictions occur (in the Gödelian sense): the fractal machine operates in a non-algorithmic way and the formal system cannot explain all about itself (undecidability). The transformation of a non-local incursive system to a local recursive system leads to a folding of each automaton to the other ones from the future time to the present time. We will show later that the internal evolutionary process can be modelled as a function of the system's state at time past, present and future with fundamental consequences for biological perfection.

### **Perfection and final cause**

The newly generated structure attains the value in changed Umwelt. This means that it is embedded in a whole system interacting with the environment as a part of a new established harmony. This is possible if a new configuration fits to a certain canon. Organism constructs itself via certain harmony principles, used also for pragmatic goals (Lyubischev 1973, 1982). The problem of form is generally not only pragmatic: it needs aesthetic criteria, primary and absolute to any concrete adaptive harmony. According to Lyubischev (1973: 46), evolution passes through the change of canons. "A small deviation from the canon is a cacophony, while a significant deviation can lead

us to a higher canon, to a new degree of beauty". Evolution of canons includes the period of initial primitivism (simplicity of form, brightness and contrast of colours), the classical period with most harmony and finely balanced forms and colours, and finally the manieristic period with some unusual and unbalanced structures. Style unity is the highest level of wholeness non-reducible either to the adaptive harmony or to the correlation between parts.

Interaction between the whole and the parts can be viewed as an intersection of the sets with different dimensions forming a contradiction in the sense of Russel's paradox (the fixed point) (Bounias, Bonaly 1997a). This intersection may represent a harmony or a disharmony, depending on how parts are observed within a whole observing it. A harmony appears as a threshold for establishing a connection between local and global periods of iteration in recursive embedding (Mignosi *et al.* 1998). When viewed as a recursion (reflected from incursion), the preceding motif unit is transferred into the subsequent one by a certain fixed similarity transformation  $g: S_{k+l} = g(S_k)$ . The resulting domains (having certain quantitative values) are hierarchically embedded into one another and function at every level with different clock time periods (Petukhov 1989). The limit of actualisation fits optimality of the structure being actualised thus it provides the existence of most optimal solutions for design.

In internal evolutionary process, which includes formation of self-referential loops, the evolving state is determined by the two (in the simplest case) contradictory values of the system separated by time interval, and the value in time future acquired after addressing them. Addressing the fixed point means that the two contradictory statements taken as sequential values separated by time interval and equally probable are composed to get the third statement. Thus the next statement (quantitatively modelled as having correspondent value) is composed from the two previous statements when they are memorised within the reflective loop:  $F_{n+2} = F_n + F_{n+1}$ . This formula corresponds to the Fibonacci series if neighbouring elements are just natural numbers. This will lead to important evolutionary consequences: in the transformation of a non-local incursive system to a local recursive system, certain recursive limits (e.g. the golden ratio,  $Q_n = F_{n+1}/F_n$  at  $n$  growing to infinity) will appear as fundamental canons of perfection formed as memorisation within reflective loops.



Other useful series appear when three neighbouring elements  $F_n$ ,  $F_{n+1}$ ,  $F_{n+2}$  are taken as lengths of three sequential segments (as appeared in the sequential past ( $t-1$ ), present ( $t$ ) and future ( $t+1$ ) times). In this case we get the golden wurf

$$W_n = (F_n + F_{n+1})(F_{n+1} + F_{n+2}) / [F_{n+1} * (F_n + F_{n+1} + F_{n+2})]$$

as a limit of the recursive process when  $n$  increases to infinity (Petukhov 1989).

The golden ratio and the golden wurf constants represent fundamental values of infinite recursion when the next element is formed by the operation on the two previous sequentially appearing elements memorised within the reflective loop. They always occur in morphogenetic patterns appearing as limits of the infinite process of recursive embedding arising from the reflective action (internal quantum measurement).

The classical description of evolutionary process views the latter as occurring in the external Newtonian time. The real evolutionary process forms time by itself — it appears as a tool for the separation of contradictory statements in the infinite embedding process. The Newtonian external time occurs when the internal incursive/hyperincursive process is transformed (via memorisation in self-reflective loop) to recursive rules. Thus originally time is a semiotic phenomenon. This view arises to Aristotle who defined in *Physica* (IV, 12) that there is the time (external) which *is* measured and the time (internal) *by* which an observer measures. Evolution in the semiotic time represents a contradictory process of growing complexity, which includes both fundamental principles of perfection of canons regarded as its nomogenetic laws in the sense of Berg (1969) — and free creativity for their construction based on internal choice in the sense of Bergson (1917).

## References

- Aristotelis 1984. *The Complete Works of Aristotle*. Jonathan Barnes (ed.). Princeton and New York: Princeton University Press.
- Baer, Karl Ernst von 1864. *Reden gehalten in wissenschaftlichen Versammlungen und kleinere Aufsätze vermischten Inhalts*. St. Petersburg: H. Schmitzdorff.
- Baldwin, James Mark 1896. A new factor in evolution. *American Naturalist* 30: 441–451 and 536–553.

- Barham, James 1990. A Poincaréan approach to evolutionary epistemology. *Journal of Social and Biological Structures* 13(2): 193–258.
- Berg, Lev S. 1969 [1922]. *Nomogenesis*. Cambridge: MIT Press.
- Bergson, Henri 1917. *L'Évolution créatrice*. Paris: Alcan.
- Bounias, Michel; Bonaly, André 1997a. The topology of perceptive functions as a corollary of the theorem of existence in closed spaces. *BioSystems* 42: 191–205
- 1997b. Some theorems on the empty set as necessary and sufficient for the primary topological axioms of physical existence. *Physics Essays* 10(4): 633–643.
- Chomsky, Noam 1965. *Aspects of the Theory of Syntax*. Cambridge: MIT Press.
- Dubois, Daniel M. 1997. Generation of fractals from incursive automata, digital diffusion and wave equation systems. *BioSystems* 43(2): 97–114.
- 1998. Hyperincursive methods for generating fractals in automata related to diffusion and wave equations. *International Journal of General Systems* 27(1–3): 141–180.
- Georgescu, Gianina 1997. On the generative capacity of splicing grammar systems. *New Trends in Formal Languages. Lecture Notes in Computer Science* 1218: 330–345.
- Gunji, Yukio-Pegio; Sadaoka, H.; Ito, Keisuke 1996. Bootstrapping system defined by inconsistent relation between Boolean and non-Boolean algebra. *Applied Mathematics and Computation* 79(1): 43–97.
- Gunji, Yukio-Pegio; Ito, G. 1999. Orthomodular lattice obtained from addressing a fixed point. *Physica D* 126(3/4): 261–274.
- Hegel, Georg Wilhelm Friedrich 1971 [1830]. *Philosophy of Mind*. Wallace, W. (trans.). Oxford: Oxford University Press.
- Igamberdiev, Abir U. 1992. Organization of biosystems: A semiotic approach. In: Sebeok, Thomas A.; Umiker-Sebeok, Jean (eds.), *Biosemiotics: A Semiotic Web 1991*. Berlin: Moyton de Gruyter, 125–144.
- 1993. Quantum mechanical properties of biosystems: A framework for complexity, structural stability and transformations. *BioSystems* 31(1): 65–73.
- 1998. Time, reflectivity and information processing in living systems. A sketch for the unified information paradigm in biology. *BioSystems* 46(2/3): 95–101.
- 1999a. Foundations of metabolic organization. Coherence as a basis of computational properties in metabolic networks. *BioSystems* 50(1): 1–16.
- 1999b. Semiosis and reflectivity in life and consciousness. *Semiotica* 123(3/4): 231–246.
- 2001. Semiokinesis — Semiotic autopoiesis of the Universe. *Semiotica* 135(1/4): 1–23.
- Kampis, György 1996. Self-modifying systems: A model for the constructive origin of information. *BioSystems* 38 (2): 119–125.
- Kolmogorov, Andrey N. 1965. Three approaches to the quantitative definition of information. *Problems of Information Transmission* 1: 1–17.
- Kull, Kalevi 1999. Outline for a post-Darwinian biology. *Folia Baeriana* 7: 129–142.

- Leibniz, Gottfried Wilhelm 1965 [1714]. *Monadology and Other Philosophical Essays*. Schrecker, P. (ed.). Indianapolis: Bobbs-Merrill.
- Lyubischev, Alexander A. 1973. The letter to N. G. Kholodny. *Priroda* 10: 46 [in Russian].
- 1982. *Problems of Form, Systematics and Evolution of Organisms*. Moscow: Nauka [in Russian].
- Mignosi, Filippo; Restivo, Antonio; Salemi, Sergio 1998. Periodicity and the golden ratio. *Theoretical Computer Science* 204(1/2): 153–167.
- Neumann, John von 1966. *Theory of Self-Reproducing Automata*. Urbana: University of Illinois Press.
- Ogryzko, Vasily V. 1997. A quantum-theoretical approach to the phenomenon of directed mutations in bacteria (hypothesis). *BioSystems* 43(2): 83–95.
- Pattee, Howard H. 2001. The physics of symbols: Bridging the epistemic cut. *BioSystems* 60(1/3): 5–21.
- Paun, Gheorghe; Salomaa, Arto 1997. From DNA recombination to DNA computing via formal languages. *Bioinformatics. Lecture Notes in Computer Science* 1278: 210–220.
- Petukhov, Sergei V. 1989. Non-Euclidean geometries and algorithms of living bodies. *Computers and Mathematics with Applications* 17: 505–534.
- Sharov, Alexei A. 1999. The origin and evolution of signs. *Semiotica* 127(1/4): 521–535.
- Turchin, Valentin 1977. *Phenomenon of Science*. New York: Columbia University Press.
- Wittgenstein, Ludwig 1953. *Philosophical investigations*. Oxford: Blackwell and Mott.

### **Семиотические основания возрастания сложности в процессе биологической эволюции**

Любая биологическая система включает внутреннее описание самой себя и существует как суперпозиция различных возможных реализаций, которая подвергается редукции в ходе взаимодействия с окружающей средой. Процесс этой редукции не может быть рекурсивно выведен из состояния системы в настоящем времени, но включает непредсказуемый выбор и требует моделирования с учетом предполагаемого состояния в будущем времени. Подобное нерекурсивное установление возникающей конфигурации после заломинания посредством формирования рефлексивной обратной связи (создающая знак деятельность) становится наследуемым рекурсивным действием. Это ведет к увеличению сложности внутреннего описания, представляющего законы генеративной грамматики системы и определяющего возможные направления открытого эволюционного процесса. Состояния биологических систем в будущем времени могут определяться с позиции их совершенства,

представляющего конечную причину в Аристотелевском смысле и обладающего селективным преимуществом. Конечные пределы развития рефлексивного процесса, такие как золотое сечение и золотой вурф, рассматриваются нами как основные каноны совершенства, устанавливающиеся в ходе эволюции.

### **Bioloogiline evolutsioon — semiootiliselt piiratud keerukuse kasv**

Iga elav süsteem kannab endas enesekirjeldust ja eksisteerib kui selle kirjelduse erinevate võimalike realisatsioonide superpositsioon, mida piiravad või vähendavad suhted keskkonnaga. Seda vähendust pole võimalik rekursiivselt tuletada olemasolevast seisundist lähtudes, kuna ta sisaldab ka ettemääramatuid valikuid — modelleerimisel tuleb seega arvestada ka tuleviku seisundeid. Mitterekursiivselt tekkinud uus konfiguratsioon areneb püüdlikult ja rekursiivselt toimimiseks pärast mällujätmist reflektiivse tagasiside tekkimise kaudu (mis loob tegevuse märgi). See omakorda viib süsteemisese kirjelduse keerukuse tõusule, mis vastavalt generatiivse grammatika reeglitele määravad avatud evolutsiooniprotsesside võimalikud edasised suunad. Bioloogiliste süsteemide tulevikuseisundeid on võimalik hinnata nende täiuslikkuse suhtes — see on lõpp-põhjuseks Aristotelese tähenduses ning võib kanda ka valikulisi eeliseid. Reflektiivsete protsesside arengu piirväärtusi (näiteks kuldloiget ja kuldpööret) vaadeldakse kui evolutsiooniprotsessides püstituvaid täiuslikkuse kaanoneid.