Membranes versus DNA

Solomon MARCUS
Romanian Academy, Mathematics
Calea Victoriei 125, Bucharest, Romania
E-mail: solomon.marcus@imar.ro

Abstract. Based on some recent arguments brought into attention by some important authors, we point out the insufficiency of DNA in explaining life and the importance of membranes in bridging this gap. We also discuss the delicate, still open problem concerning the mathematical status of membranes.

1 DNA computing, between chemistry and biology

 Usually, DNA and RNA are considered to belong to the chemical component of the genetic language, while the genetic dictionary, associating amino acids to codons, leads to the biological, effectively genetical component, represented by proteins and determining a specific type of metabolism. On this basis, we can assert that DNA computing is a kind of chemical, rather than biological computation.

 In this order of ideas, it may be useful to mention the distinction proposed by Ji [5], between two kinds of DNA-based computers: (1) truly molecular computers (TMC) wherein all the computational operations (i.e., input, output and state transitions) are driven by self-organizing ('self' – meaning 'spontaneous' or 'internally driven') chemical reactions and molecular motors; and (2) quasi-molecular computers (QMC), where most, if not all, of the input and output operations and state transitions are driven 'externally' by macroscopic agents such as human beings or robots. Ji ([5]: 123) considers that the DNA-based computing system developed by Adleman in 1994 is an example of QMC, and not TMC, since he had to synthesize 20-mer DNA sequences by himself, carry out splicing and amplification reactions on them, and separate and purify their products using conventional molecular biological operations on a macroscopic scale. At present, concludes Ji ([5]: 124), the living cell remains the only TMC known. Are we, with TMC, nearer to biological computation?

2 “The RNA scenario suffers from serious problems”

In the recent years, more and more claims try to establish the limits of the explanatory capacity of DNA and RNA, in respect to the phenomenon called 'life'. “Contrary to the general image created by textbooks, there is no simple relation between the DNA coded messages and the construction of the organism, whether single celled or multi-cellular” (Hoffmeyer [2]: 285). “First, DNA is not self-reproducing, second, it makes nothing and
third, organisms are not determined by it” (Lewontin [7]). “DNA does not contain the key to its own interpretation” (Hoffmeyer [2]: 285). The importance of DNA and RNA is never negated. The so-called “code-duality” (Hoffmeyer and Emmeche [4]) refers to the fact that living systems always form a unity of two coded and interacting messages, the analogously coded message of the organism itself and its re-description in the digital code of DNA. We can observe here how continuity and discreteness are associated in this process. Following Hoffmeyer [1], this code-duality is a unique feature of living systems and a defining criterium of being alive.

However, as Kauffman [6] has pointed out, “the RNA scenario suffers from serious problems”. Kauffman observes that the chemical preconditions for the RNA-scenario are far from obvious and points to more theoretical considerations, contradicting the idea of simple RNA-life. The simplest existing free-living cells, so-called pleuromon, are highly simplified exemplars of bacteria containing an estimated number of genes of a few hundred to about a thousand. Viruses, which are vastly simpler than pleuromon, are not free-living. Kauffman ([6]: 42) rises the question: “Why can’t a system simpler than pleuromon be alive?” Based on his work with mathematical modelling of “combinatorial chemistry”, Kauffman concludes: “The secret of life, the wellspring of reproduction, is not to be found in the beauty of Watson-Crick pairing, but in the achievement of collective catalytic closure”.

3 Membranes in the center of the attention

Following Salt (10]: 159), a system has agency with respect to some process if its effects in the world leave a trace of its individuality. Hoffmeyer ([3]) agrees with Kauffman that the achievement of collective catalytic closure is a necessary first step for agency to be realized, but he considers that at least four more steps are needed, so we get a total of five necessary steps on the road to the origin of life and agency:

1. Autocatalytic closure (Kauffman);
2. Inside-outside asymmetry (closed surface);
3. Proto-communication (a community of surfaces);
4. Digital redescription (code-duality);
5. Formation of an interface (inside-outside loops).

So, as Hoffmeyer observes ([3]: 39), “the missing element in Kauffman’s scheme of things [...] is the idea of the surface as an ontologically primary entity, a natural kind, i.e., the idea that life is fundamentally based on surfaces inside surfaces”.

As we can see, membranes are involved in four of the above five steps. The scenario above calls attention on the fact that “the closure of a membrane around some autocatalytic chemical reaction system is an attractive candidate for a first step towards the origin of a living system”.

In respect to the asymmetry pointed out in step 2, Hoffmeyer ([3]: 35) starts with the hypothetical asymmetry of the relation organism-environment, according to which “the organism has a point of view”, while “it doesn’t feel natural to ascribe a point of view to the environment”. It is quoted in this respect Nagel [8], who criticizes “the belief that

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reality is in a narrow sense identical to objective reality”. We reach the same difficulty which appeared in quantum mechanics.

4 The asymmetry produced by any closed membrane

How do we address the problem of the legitimacy of the organism-environment asymmetry, taking into account that nature is replete with (living) systems having points of view? The inside-outside distinction becomes here essential. Hoffmeyer observes ([3]: 36) that what is outside actually always tend to be inside something else, and what is outside at one instant of time may be turned inside at a later time (as is for instance the case during early embryogeny in mammals when an invagination in the spherical stage of the blastula gives rise to the internally layered stage of the gastrula). Important are the following considerations (Hoffmeyer [3]: 36):

Yet at a more fundamental level insides are always defined by the boundary surrounding them, and in living systems such a boundary (e.g., the cell membrane or the skin) is itself a physical structure of a certain thickness and internal structure. From the point of view of the membrane or the skin even the ‘inside’ of the organism will in principle be an ‘outside’.

And this may well be the key to a solution to the organism-environment asymmetry problem. Life is built on a fundamental asymmetry, but this is not an asymmetry between organism and environment. Instead it is an asymmetry produced by any closed membrane (e.g., the skin) which separates the world into two equally excluded parts: an internal part and an external part. The membranes of living systems – at whatever level, i.e., whether they encircle sub-cellular organelles, cells, tissues, organs, or organisms – are in fact best described as interfaces facilitating a highly regulated exchange of signs between interiors and exteriors. Life should fundamentally be seen as organized around the nested set of membranes or interfaces which we call organisms.

This long quotation suggests how complicate are the problems concerning the theoretical status of membranes and their typology.

5 The mathematical status of membranes

Is the membrane under the action of Jordan theorem in topology, claiming (roughly speaking) that any closed simple surface separates the space into two domains, one bounded and the other unbounded, having the given surface as their common frontier and such that any traffic along a curve, between the respective domains, obligatory meets the frontier? The answer will depend on some further assumptions and a mathematical typology of membranes seems to be a necessary preliminary step, including also the possibility to assimilate the membrane with a fractal object.

There is a rich terminology which covers situations of the membrane type: frontier, boundary, margin, interface, border, periphery, singularity surface etc. Maybe membranes have something from each of them, but equally probable they can be reduced to none of them. Topology is deeply involved in the mathematical modelling of these situations (general topology: frontier; algebraic topology: border; differential topology: singularity surface or catastrophic surface).
Membranes, between the Mobius strip and the Klein bottle

There is another, more delicate aspect. As Heinz von Foerster observed in an interview with Gertrudis van der Vijver [11], the Mobius strip could be the right topological representation of the kind of logic pertaining to self-referential cybernetic systems. We recall that for the Mobius strip inside and outside are co-extensive, so that there is only one side. In contrast with usual surfaces, having two faces or two pages, the Mobius strip has only one page; but it still produces an asymmetry between interior and exterior, so we can speak of an inside exterior and an outside interior. Hoffmeyer [1] claims that one of the keys (the other being the code-duality) to a theory of the origin of life or subject-ness is a process of asymmetry-formation through membrane closing followed by the development of mechanisms for semiotic interaction across the membrane. It is the semiotic dimension which accounts for the paradoxical categories of the “inside exterior” (Uexkull’s “Umwelt”) and the “outside interior” (Hoffmeyer’s “semiotic niche”).

Maybe, the Mobius strip should be replaced here with the Klein bottle, where the inside-outside distinction is transgressed in a more intuitive way. Both the Mobius strip and the Klein bottle became cognitive metaphors of high creative capacity, the former being involved in the art of Escher, while the latter was used by Claude Levi-Strauss in connection with his canonic formula of myth.*

The aspects pointed out above bring new arguments in favor of the high explanatoriness of the membrane and will perhaps suggest new, alternative points of view in the field of computing with membranes, initiated by Gheorghe Păun [9].

References


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