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Evolutionary Computation and the Processes of Life

Information, Biological, and Evolutionary Computing

by Walter Riofrio

Editor's Introduction

In this article, Walter Riofrio highlights some of the open questions about relations between biological and evolutionary computation, trying to show that a careful analysis of how life evolved could support new developments in the evolutionary computation model.

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Commonly, evolutionary computation is often inspired by biological mechanisms of evolution such as genetic algorithms, evolutionary strategies, evolutionary programming, among others. But all of these evolutionary models of computation are developed from within the framework of Darwinian evolution, also known as "vertical evolution."

For the purpose of this symposium, I would like to highlight that Darwin's ideas are only a part of the story of evolution. In particular, the fact that at present there is a growing body of scientific evidence indicating that biological evolution is not only vertical, but massively horizontal—the so called Horizontal Gene Transfer (HGT) [1].

The difference is clear, in one case the genetic material is transmitted "vertically" from the parents or ancestors to its offspring. In the other case, the genetic material is "acquired horizontally" from other organisms around them.

The main thrust of this article shall focus on a series of possible foundational and theoretical aspects arisen from a new research area that is potentially interesting to this symposium: The evolutionary consequences of a proposal about the cellular origin of prebiotic evolution [2, 3].

Origins of Prebiotic Era

Current research indicates it is reasonable to assume we will never know what kind of molecular compounds were exactly involved in the processes of adaptation and evolution of first prebiotic systems. However since the 1990s, it has been reported that asteroidal and cometary material by the early Earth may have been a source of organic matter that was necessary for the advent of life [4].

Taking into account the current understanding about what the conditions of primitive Earth could have been like and meteor impacts during this time period, it is possible to theorize the feasibility of the existence of molecules of prebiotic interest such as amino acids, nucleobases, monocarboxylic acids, sugars, and polycyclic aromatic hydrocarbons [5].

It is reasonable to postulate that the chemical compounds found in primitive Earth would have mostly been very simple in nature, and would have been immersed in the natural dynamics of the physical world, some of which would have involved self-organization.

When we are in the pursuit of trying to understand how simple molecular structures within specific molecular processes could produce the emergence of a cellular system, a more valuable approach may be where self-assembly processes and self-organization are the key requirements rather than looking for isolated macromolecules (like DNA or proteins),

We then need to highlight both the synchronization phenomenon and the correlation between processes—both of which are necessary to ensure sustainable growth in protocells, which will be necessary to attaining evolvable capacities. Remarkably, correlations between processes can be attained when a system is in a far from the thermodynamic equilibrium state. In this condition, the time evolution of protocells could show an array of feedbacks, nonlinearities, and the appearance of patterns that are unequivocal signs of correlation between processes [6, 7].

I additionally hold the dawning of the prebiotic world implied formation of a self-organizing dynamic that, in reality, was a determined type of protocell. It emerged in the remote past, thanks to the correlation produced among three very different types of molecular processes, two of which act as different system constrictions [8].

The model I propose consists of at least two correlated processes whose states would cause the emergence of two basic characteristics of living beings: (1) the system is maintained separate from its environment, and (2) it is self-maintaining, being driven by its own dynamics away from thermodynamic equilibrium. It would be a kind of dissipative structure.

These two processes will have been highly interconnected, as they shared a chemical compound. This would have been a kind of high-energy compound, because it had to have had a large negative free energy of hydrolysis. It would have served as the ancestral “energy currency” molecule.

The third group of processes is a network of reactions that would perform the regeneration of the organizational dynamic, maintenance, and reproduction processes of this prebiotic system.

My protocell proposal is therefore organized by the interdependence of three sets of processes, and we know that a correlation among processes is to be expected whenever a system is in a far from thermodynamic equilibrium state.

What is interesting here is that each process, left by itself, has no evolutionary potential. Yet, when they are interrelated, they trigger the appearance of an entity that contains a certain level of interaction with its surroundings—it behaves as an autonomous agent [9].

This provides it the capacity to adapt to its environment—it is a complex adaptive system—and, hence, it would have the ability to evolve (while this trait would have been minimal at its start up).

In addition, my protocell model contains properties that would not have been found within the process types that form it if those were separated one from another. This interdependence to which we are alluding has to do with the three process types that interact amongst each other so as to become a self-sustaining and self-maintaining molecular network of processes vis-à-vis an ever-changing environment. In other words, this protocell would have already contained within itself a certain degree of minimal complexity that could not be reduced into its parts or constituents.

On the other hand, it is important to highlight that there is a growing recognition that life is distinguished from the nonliving by its dependence on signs [10]. And when I was building my model of an early prebiotic system, concomitantly, a view of signs as phenomena that appear in the physical world from a very special and specific relationship arose.

My line of reasoning follows from the fact that whatever kind of energy variation may occur in a biological system, it will only turn into a sign (it will become "potential information" for the system) when the system has the capability to react accordingly. And this happens when the energy variation impacts something in the system and is incorporated into the system—as a variation—with the capacity of becoming part of the system's processes.

If an energy variation does not have the capacity to be incorporated in the form of a variation (any kind of variation) in the system, then it is not a sign for the system, and, as a consequence, the system cannot develop a response. Therefore, I claim this is the form in which signs emerge from physical reality.

In consequence, our proposal concerning conditions in which it is possible for biological information to emerge finds its roots in the dynamic transmission of matter-energy variations.

Later on, after these variations are incorporated into a dynamic entity that can detect them (it turn into a signs for the system) and that also contains the ability to form some type of response in tune with them; the signs then become completely meaningful information for that dynamic entity (biological system or, in our case, prebiotic system). We propose the following: Information emerges in the biological world as "information with meaning" or "meaningful information."

To be exact, it emerges as information with biological meaning or what we like to call "bio-meaning."

Like signs, information is also a relational notion, and as such it will depend on processes, specifically biological processes. Information will always be meaningful information for biological systems.

Since our protocell paints the picture of the dawning of the prebiotic world and given the emergence of biological information and the existence of the internal constraint, which secures a far from thermodynamic equilibrium state for the protocell, we find ourselves in a place where we can conclude the system will, through decentralized processes, behave in ways that may be related to different externally and internally generated signs.

This bio-meaning (generator of protocell behavior, i.e. type of response) is the result of the transmission of a "variation"—originating from a matter-energy variation that affected the system—that travels across the protocell's processing network and ends up producing a consequence that will increase, maintain, or decrease the far from thermodynamic equilibrium state.

We might be able to assign to this matter-energy variation, transmitted across the molecular mechanisms involved in the system's processes, a relationship or link to what could be the way in which the biological world "computes."

We now grasp that the protocell's interdependent processing network has produced an interesting phenomena; since, fundamentally, its two self-constraints are especially interconnected, the matter-energy variation (regardless of which process kick started the transmission) will inexorably conclude as a micro-cycle formed by endergonic- exergonic processes (the self-constraint), turned into an unavoidable checkpoint along the pathway of creating a future set of responses that are generated in another part of the interconnected and interdependent processing network.

In addition, it may provide us the necessary tools to begin looking at the related question of how a sort of "relative reference point" that enabled the development of "something to be greedy about" on the routing paths of the biological small-world could have emerged as core characteristics to the way in which the biological realm computes [11].

Early Evolutionary Dynamics

I would point out, although acknowledging the importance of taking into account that biological evolution (as usually supposed) requires mutation, selection, and replication, viewed from their origins, these functions would not necessarily have been closely interdependent. In particular, it would be possible to completely dissociate the source of selective advantage from the process of molecular replication [12].

Focusing our quest on the initial systems in prebiotic times, we ask ourselves what kind of necessity imposed natural selection and precluded the use of other reliable mechanisms of evolutionary change. We need to be aware that there have been times when we would hardly be able to find a molecule remotely resembling DNA, RNA, or even proteins. It is not fitting, therefore, to claim that evolution by natural selection was the evolutionary form involved in the adaptive changes of the different systems that appeared in those early times. Thus, it is feasible to propose that in the dawn of the prebiotic epoch there would have been a different type of evolution that subsequently introduced evolution by natural selection.

On one hand, outcomes from completed comparative studies seem to suggest the three great cellular designs we are currently managing did not simultaneously achieve the state of modern cells. A situation that would imply being in possession of the sufficient macromolecular arsenal required for replication, transcription, and genetic translation mechanisms [13].

So, cellular entities that lacked the capacity to establish evolutionary lineages might have been the ones populating the epoch prior to the one in which materializing was the new cellular organization so called modern cells contain. As a consequence, the most important evolutionary motor during that remote, previous time period could have been Horizontal Gene Transfer [14].

What is more, on account of the fact there was no sort of heredity between parent and offspring cells, the time it took to pass through the stage of the origin of modern cells is also the time in which we can see the appearance of the capacity for possible species genesis.

Moreover, we must respond to fundamental questions in order to understand cellular evolution, and the most important of these makes reference to the origin of the great many novelties needed for constructing the incredibly coordinated, macromolecular scaffolding that constitutes modern cellular organization [15].

In order to be able to grasp the most important connections between evolvability and evolutionary innovations that occurred at the beginnings of the prebiotic era, we should ask if a prebiotic system proposed by me could be evolvable in terms of generating novel variations through the acquisition of new functions.

The "ability to innovate" (and then to evolve) in my protocell model is due to its sustained and robust intrinsic dynamic self-organization. Because this system has the capacity to stay in a far from thermodynamic equilibrium state by itself, within its dynamic self-organization, we could hypothesize that its "innovative potential" cannot be governed other than by its cohesive dynamic way of existing.

Once these systems are confronted by a specific, environmentally-generated problem, the different possible solutions (strategies), produced in the system's protoplasmic membrane as a product of the reproduction of these systems, are nothing more than the maintenance of the integrity of their dynamic organization, i.e., the maintenance of the close interrelation between the three kinds of processes.

The components of a system could be changed but, as a whole, the system's descendants would tend to preserve their most fundamental properties that are compatible with their survival in conditions, and they are far from the thermodynamic equilibrium state.

So then, what was the type of evolution during the dawn of the protocell era, during the emergence of a cellular system with the kind of self-organization as sketched in my conceptual model? Although we are dealing with times when HGT had not yet evolved in populations of protocells, it would be valid to try to imagine some of possibilities that would give some clues concerning the causes involved. What kind of evolution was taking place before and leading up to the HGT?

As with evolution prior to the appearance of the domains of bacteria, eukarya, and archaea, which was mainly governed by HGT, reproduction of these initial groups of prebiotic systems was dominated by some type of horizontal capacity and novelty exchange that enabled them to adapt to ever changing and completely hostile surroundings.

In other words, appearance of a prebiotic, adaptive evolution would have involved some type of component or process exchange that would have produced a benefit or maintained these systems in the far from thermodynamic equilibrium state. Thus, of all the mechanisms that have been identified one could postulate, the more plausible would be that more primitive forms of gene transfer agents were acting in earlier exchanges of the protocell's genetic material.

Taking into account my proposal and these facts, I could argue a possible scenario for the times in which started the prebiotic world. More precisely, we hypothesize that in those remote times emerged a kind of self-organizing dynamic structure containing very special capacities. A community of protocells able to interact, exchanging materials, increasing to some extent its response to environmental changes, and so, triggering the activation of signaling networks, claims to.

In the first place, they must have had the capacity to send and recognize signs. In the second place, those simple mechanisms that were involved in the communication of this very ancient community of protocells might have been the roots of what could be the way in which these molecular dynamics had provided the conditions for the emergence of the first small world structures [16].

Furthermore, sharing certain components and structures acquired and transmitted through these sources possibly was the way the most ancient populations of protocells evolved. Maybe this was the way novel structures, components, molecular networks, characteristics, properties, and the like would be generated by first dynamic protocells.

These last references give us an indication of how (i) the fundamentals of signaling networks, (ii) the first appearance of prebiological agency, (iii) the emergence of biological computations and small world structures in communities of protocells could lead us to propose a Lamarckian form of inheritance in the dawn of prebiotic evolution [17].

Concluding Remarks

We claim that signs in biological systems (and in pre-biotic systems as well) are related to matter—energy transformations as they are incorporated into the system as "variations." In turn, these variations become biological information—always with bio-meaning—because they impact cohesion, maintaining, increasing, or even decreasing the far from thermodynamic equilibrium state.

From the dawning of the prebiotic world, one of those traits the primordial protocell had was the capacity to compute. Additionally, this incredibly distant period in time may be when we can see the appearance of the first small world structures as core characteristics to the way in which the biological realm computes.

At the same time, my proposal on the origins of prebiotic protocells supports the conclusion that it is very likely that some kind of "horizontal-like" evolution may have been the rule in those remote epochs. And this is another way to point to a kind of evolution very similar to the Lamarckian model.

If one wants to imitate natural biological processes using the way nature discover adaptive pathways, then adding this evolutionary mechanism to solve problems in computers could be a new way of monitoring and observing the behavior of evolutionary computations.

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About the Author
Walter Riofrio's research is related to theoretical and evolutionary biology under the umbrella of the sciences of complexity. In particular, his interests lie in studying time periods before the origin of living systems, or in other words, in the pre-biotic era. Riofrio is also interested in studying the emergence of cognition from an evolutionary point of view. He has published works on these topics in journals and as chapters in different books. His first formation was in biochemistry, while his later doctoral studies were in philosophy.

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