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Life Origins and the System. Changing our Perspective

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Yitzhak Tor has, in this issue, made an ardent plea for a paradigm shift away from "traditional" (ie: post Miller-Urey) approaches to abiogenesis research and prebiotic chemistry in particular by embracing the *systems* view. His plea is, in my view, most timely and well-founded. The time is certainly ripe for new ideas, new players and new connections in the field if life origins.

As Professor Tor points out, contemporary biological cells (and presumably the Last Universal Common Ancestor, LUCA) are complex interconnected networks of chemical processes[1] whose dynamic and periodic fluctuations constitute a far-from equilibrium system. By adopting therefore systems view of living, we are in effect, changing our optic on the problem and it is this change that I believe will ultimately prove to be of great value.

As chemists, when we look at biological life, we see chemicals, of course! We see reactions between them, exchanges of energy from one part of system to another and between the system and environment. We see also, the intricate and regulated mechanistic interplay between large molecular ensembles (DNA, RNA, Ribosome) leading to the synthesis of new classes of large molecular assemblies (proteins), which subsequently have some functional value to the system itself. We ask how these molecules came to be, why these reactions and not others, how is the complex interconnectedness of the system built and regulated. These are most valid questions, yet the traditional prebiotic chemistry tool in trying to answer such questions is reductionist and such a method has a rather fine-grained optic. Adopting a systems approach allows for a more coarse-grained view of the problems.

Professor Tor cites several seminal markers in this new view of abiogenesis that pioneers such as Benner, Sutherland, Powner, Pross and many others have planted for our benefit. What happens when we widen the optic a little further? If instead of the individual chemical processes and molecules, we look at the system at the cellular level; what is the system doing? Chemicals go in and other chemicals go out; energy from the environment flows through the system and is transduced to chemical energy currency molecules (such as adenosine triphosphate in contemporary cells). The (cellular)system has motility within its environment searching for energy and chemical blocks for its own construction. The system grows; and at some point divides, multiplies and growth becomes associated more with a cellular ensemble than with the individual component systems. The *system* changes and, indeed, so too does the environment.

A focus on energy transduction, as flagged up above, is one that provides several valuable insights in my view. Biological (cellular) systems are essentially complex chemical factories for the dissipation of energy from one form to another. They are, as Prigogine pointed out, examples of far-from-equilibrium arrangements whose thermodynamic properties conducive to building complexity[2] through stochastic, spontaneous, self-organizing behavior. Prigogine called such arrangements, dissipative systems and they allow us to widen the optic of the systems view even further. Prigogine illustrates this himself by pointing out that dissipative systems are not solely the province of biology, but can be found all around us: rivers, volcanoes, civilizations, cities, weather patterns, our own planet, our solar system, galaxy clusters and our universe itself. All such structures share a common drive towards transducing energy, and using some of that energy to build complex arrangements through spontaneous self-organization of mutually interacting elements; molecules, fluid droplets. Cloud formations, sand or dust particles, banking systems, communications networks, stars and galaxies. In so doing, the system is better able to increase the overall entropy (or information, to which entropy is intimately connected mathematically)[3] of the universe in compliance with the second law of thermodynamics. What differs between these different exemplars of dissipative arrangements is the *mechanism* by which they achieve the same overall goal.

How does this then offer us the opportunity to change the granularity of our optic even further? Allow me to throw out a suggestion: how does our view change if we consider all such dissipative structures as being examples of living processes? What then is the distinction between living and non-living systems? Is there in fact a distinction at all; is all alive? If we consider all matter and radiation within our universe to be examples of far-from-equilibrium systems, then everything becomes capable of living on the grounds that they can be, or be the agency of, transducing energy and driving spontaneous, yet contingent self-assembly. What then is the relationship between *system* and *environment* in this model (for there are no non-living arrangements in this view)? It joins both inextricably. The system-environment composite is in essence what makes everything alive. The two are mutually linked so that the symbiotic relationship between them is what is actually living. Changing one will lead to changes in the other. The two change together.

Indeed, if then system and environment are conjoined, where are the definite boundaries? The true boundaries are not hard physical ones, but rather are gradients of energy transduction mechanisms which operate over a range of temporal and spatial lengths. What then of evolution? Evolution, or contingent stochastic change in my model above, is then when the mechanism(s) by which one system-environment composite transduce energy, change to different mechanisms. Some changes may benefit the dynamic kinetic stability of that system-environment composite, others may not.[4]

What then of life in this model? It is not so much a structure or a thing, it is the process by which structures or things interact; from which spontaneous self-organisation emerges and change is driven. In this regard, it may be more valuable to consider *living as a dynamic field of multiple contiguous dimensions* where dimensionality is not so much physical or temporal as in general relativity, but represent fluid mechanisms by which energy can be transduced and self-organisation emerge.

In summary, the change in optic from contingent chemical/reactions to integrated chemical systems is a step-change with enormous potential. By broadening the granularity of vision through which to view life origins and the process of living it allows us to blur certain “boundaries” whilst focusing on the dynamic connectivity which drives change. Perhaps the systems view will help illuminate some of the foot-hills in formulating a general theory of living.

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