

Systems Theory and Astrobiology. N. J. Woolf, LAPLACE, Steward Observatory, University of Arizona, Tucson AZ 85721 (nwoolf@email.arizona.edu)

Introduction: The origins, evolution, distribution, and future of life in the universe are all complex processes. They are the operation of systems in environments, and Systems Theory is a work in progress to deal with both the complex and simple aspects of how such systems operate. Von Bertalanffy [1], the developer of Systems Theory stated "...there exist models, principles, and laws that apply to generalized systems or their subclasses, irrespective of their particular kind, the nature of their component elements, and the relationships or "forces" between them. It seems legitimate to ask for a theory, not of systems of a more or less special kind, but of universal principles applying to systems in general."...

The breadth and topics of astrobiology provide a fertile testing ground for exploring systems concepts. But the prime justification for going to Systems Theory is the inability of astrobiology to move forward on the question "What is life?" It is an expression of an inadequacy, a failure of underlying concepts and methodology that wreaks havoc on the attempt to develop answers to questions about origin, evolution, distribution and future, and requires a new approach to thinking about these topics. This is where Systems thinking offers a possibility of breaking out of our mental box.

Roles: Let us reconsider the nature of complex processes such as life, and start to see them as a hierarchical development of roles. I am part of a group that is trying to explore such a hierarchy of roles, see Dennis et al.[2] Note that in that work the roles are called "ramps" because they contain within a given role, a scope for some development in the interaction with lower roles. Those roles are all required in any development of a system, but the number of roles increases as the complexity of process increases, so there are 3 role systems or 7 role systems etc. The overall process is a kind of cooperation between "the thing" or system and its environment. The roles involve both the environment and the system. Roles need not be exclusively the province of a single system, but may be distributed between multiple systems. However, no role may be developed or maintained without its supporting roles being present to sustain it. An example is the role of a hereditary pattern. A hereditary pattern needs to be sustained by a role of cycles that transport energy and maintain a chemical environment. That role we call metabolism. In a virus most of the metabolism role is played outside the package with the hereditary pattern. Likewise the role of metabolism needs to be supported by other roles that include transport of matter and energy.

The justification for the given set of roles and no others is a task for Systems Theory, and it seems to lie deep in the nature of existence. However Astrobiology can help in this task by being alert to finding roles other than the eight known to our group. Seeking exceptions is an important part of validation or rejection.

Another theoretical aspect is that the structure of roles can only be supported by this same structure, so the development of each role follows the same sequence that gave rise to the role itself, and those sub structures have the same basic sub-sub-structure.

We see the same lower roles occurring with a wider variety of circumstances when upper roles are missing. Thus metabolism-like roles are played in hurricanes, crustal convection in the Earth and nuclear reactions and energy transport in the Sun. Higher roles can attach to these processes or to other ones, but underlying all process is energy flow. The flow of energy is the simplest role that exists in an environment. But energy is transported as a sequence of quantum events. These have no continuity. The characteristic of the successful addition of upper roles is that they add continuity. Each role has an intrinsic limitation to it being sustained. The addition of higher level roles allows continuity by adding, substance, coherence and motion to permit cycles to be sustained.

The Darwinian view of survival is of survival and modification of a hereditary role, not of the individuals that are currently playing the role. To this we add that although modification is not possible if there is no hereditary process, survival is a necessary part of sustaining the lower level roles also. Survival of lower roles is necessary for the development of higher roles. The dependence on lower roles provides a benefit to upper roles when they modify and improve the sustaining of the lower roles they depend upon. Cooperation between roles is the nature of the game.

The Questions of Astrobiology: Questions about the origin of life deal with six roles that must be fulfilled: energy flow, material basis, cohesion, matter flow, cycles and development of a hereditary shaping structure. In particular, origin of life deals with issues of how sufficient complexity can arise to permit the development of a hereditary shaping structure. It could in principle arise in an otherwise inadequate environment by being implanted from a development that arose elsewhere. This must be borne in mind in not eliminating from search environments that could sustain but not initiate ramp 6 roles. But from a cosmic perspective the most interesting issue is how ramp 6 roles arise without intelligent direction, using the directivity built into the nature of the physical world.

Questions about the evolution of life deal with the shaping of and by the structure playing the hereditary role. But also they deal with the possibility that the coherence of individual units in which hereditary structures arise will permit additional developments, such as nervous systems. And nervous systems are associated with a role of survival in a world with other hungry nervous systems. There is a further role in which nervous systems construct durable memories outside their bodies, books etc. so permitting complex processes to

be performed with the benefit of the experience of prior generations. It is that process that will hopefully guide the development from where we are to where our effective descendants need to be. I say "effective" descendants because it is possible that the highest role will break away from its current underlying physical basis, so permitting spaceflight that lasts extremely long periods with a totally dormant organism capable of self repair of that which has been destroyed during flight.. This would remove role 8 from the limitation of continuing around a star with finite lifetime.

Conclusion: Scientific fields such as Astrobiology and Systems Theory deal with the realities of a complex existence. They are also potentially extremely helpful to humanity because they deal with issues of how humanity can sustain itself as its understanding and technology grows faster than it develops its self control. It may be significant that in the current development of the underlying theory the rate of development is the solution of a quadratic equation. One root leads to exponential growth of the new role. The other leads to exponential decay. The search for intelligent life in the universe is a search for organisms that selected the first root.

References:

- [1] Von Bertalanffy H. (1968) *General Systems Theory* George Braziller, NY 1968
- [2] Dennis L. et al. (2008) *Foundations of Science* **14**, 217-238.(2009)