 Emergence: Complexity and Organization.

A form of logic suited for biology

June 30, 2005 · Classic Paper

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Elsasser W, Goldstein J. A form of logic suited for biology. Emergence: Complexity and Organization. 2005 Jun 30 [last modified: 2016 Nov 23]. Edition 1. doi: 10.emerg/10.17357.184fcd8230600c428deca361c2761278.

The organized complexity of living organisms: Walter Elsasser's contributions to complexity theory

A nonlinear life and career

The work of the German/American physicist turned theoretical biologist Walter Elsasser (1904-1991) is unfortunately little known today even though he made important discoveries in several scientific fields and played a key role in introducing the notion of *organized complexity*. Elsasser's conceptualization of this idea paralleled its elaboration by Warren Weaver after WWII (see Weaver's article "Science and Complexity" in issue 6.3 of *E:CO*). We at *E:CO* would like to start remedying this lack of recognition of Elsasser's seminal contributions to complexity theory by offering one of his key papers on organized complexity in biology. We're not doing this merely out of a desire to fill-out the historical record. Rather, we also believe that a careful reading and contemplation of Elsasser's main ideas can yield a sense of both how the sciences of complex systems have developed and where they might grow in the future.

The pattern of the life and career of Elsasser can itself best be appreciated as a nonlinear complex system because of its many unexpected twists and turns as well as the ample creative adaptations it took. Elsasser went from significant theorizing in atomic physics (including electron scattering and the shell structure of atomic nuclei), geophysics (specifically magnetohydrodynamics), atmospheric physics, solid-state physics, and then later turned his attention to theoretical biology. Along the way he became the recipient of numerous prestigious scientific awards.

In his memoirs of Elsasser, Harry Rubin (1995), points out that Walter had attended the University of Göttingen where he came into contact with such eminent physicists as Max Born, Paul Dirac, and J. Robert Oppenheimer. Göttingen was also a major center for mathematics being the academic home of the great German mathematician David Hilbert. This gave Walter the opportunity to also meet and form life long associations with two of the giants of twentieth century mathematics, Norbert Wiener and John von Neumann (who was Hilbert's assistant), both of whom played key roles in the development of the system sciences of cybernetics, information theory, and computer science. In fact, Rubin says that Elsasser's encounter with von Neumann's *The mathematical foundations of quantum mechanics* helped lead Walter to the conclusion that the introduction of probabilities into physics, a distinctive feature of quantum mechanics, did not so much 'loosen up' the framework of the theory, but made it even more deterministic and thus more suitable for reducing everything to physics than Newtonian mechanics had ever been. Prof. Elsasser grew to become even more deeply dissatisfied with reductionism, especially as applied to organisms. It took some twenty years of this struggle with quantum mechanics for Elsasser to propose a radical disjunct between the infinite sets underlying mathematical descriptions at the basis of physics with the finite sets of observations that the experience of biological organisms offered. Organisms, according to Elsasser, took the form of a heterogeneity or individuality which set the organic life apart from the inorganic world.

Studying later in Berlin, Munich, Leiden, Paris, New York, Ann Arbor, Chicago, and Los Angeles, Walter also became friends with other great scientists of the time including: Eugene Wigner, Leo Szilard, Erwin Schrödinger, the chemist and philosopher of science Michael Polanyi (who was himself an espouser of emergentism), Werner Heisenberg, H. A. Lorentz, Paul Ehnrenfest, Wolfgang Pauli, Hermann Weyl, I. I. Rabi, Harold Urey, Enrico Fermi, Arthur Compton, and Robert Millikan. This is quite a list! And that was just in physics not to the mention all the other eminent scientists and mathematicians Elsasser became friends over his long and fruitful career.

Physics vs. biology: From homogeneity to heterogeneity

Emergentists of what I have elsewhere called the "mid-phase" period (Goldstein, 1999) suggested that if complexly organized living organisms displayed a building-up rather than tearing down of order, as they obviously and incontrovertibly did, there must be something going on with this complexity that obviated a simple transposition of classical thermodynamics into the realm of biology. Elsasser admitted that while on the surface it did appear life abrogated the Second Law, this surface look was based on an overly simple way of understanding biological organization. To replace this overly simplistic point of view, Elsasser offered his own version of an organicist philosophy of science which characterized the complexity of organisms in terms of a radical *in* homogeneity instead of the homogeneity found in how subatomic particles like protons or electrons were understood. That is, the latter were all identical in whatever substance they could be found. It was this homogeneity that allowed for the use of purely deductive probability rules in the statistical mechanical interpretation of entropy increase.

In contrast, Elsasser defined something he called "intrinsic" and "irreducible logical complexity" in terms of (see Elsasser, 1966; also see Polanyi, 1958):

1. an asymmetry between mechanistic and autonomous components – this corresponded to the asymmetry between the macro-variables and the immense reservoir of micro-states;
2. an integration or wholeness "whose origin in physics he has every right to consider as being rather obscure" – this integration could be understood in terms of the relationship of the individual to its class (discussed in his article below);
3. the fact that complex structures contained elements that unlike in physics were different from each other – biology dealt with the individual – even the classes grouping these individuals were heterogenous. As the eminent French historian of philosophy and science, Etienne Gilson (1966), pointed out, for Elsasser *inhomogeneous individuality* could be considered a metric of how complexity increased up the biological hierarchy.

According to Elsasser it was the unique individuality of a life form and its parts which demanded that their "regularities can be neither proved nor disproved on the basis of the laws of physics." Whereas physics and chemistry could, in principle, explain every detail in the functioning of an organism, they could not explain its existence. Although his distinction between existence and functioning was not particular illuminating – given the fact that in the case of an emergent organism its unique type of existence is its unique type of functioning as Whitehead had pointed out in his *Process and reality* – Elsasser did offer the very important emergentist suggestion that an adequate account of the living must take into consideration the manner in which life will always prove elusive to explanations couched entirely in terms of physics and chemistry.

Four principles of Elsasser's approach to complexity

We can summarize Elsasser's contribution to theoretical biology by appealing to Rubin's description of four fundamental principles in Elsasser's approach:

"The first principle is ordered heterogeneity. Combinatorial analysis shows that the number of structural arrangements of atoms in a cell is immense; that is, much greater that 10^{100}, a number that is itself much larger than the number of elementary particles in the universe (10^{80}). But biology shows us there is regularity in the large where there is heterogeneity in the small, hence order above heterogeneity. This concept of ordered heterogeneity was first introduced by the molecular biologist Rollin Hotchkiss, systematized by the embryologist Paul Weiss, but given quantitative definition and set in a general theory by Walter.

The second principle is creative selection. *A choice is made in nature among the immense number of possible patterns inferred in the first principle. The availability of such a choice is considered the basic and irreplaceable criterion of holistic or non-mechanistic biology. The term 'creative' refers to phenomena that, like everything in biology, are compatible with the laws of physics but are not uniquely determined by them. No mechanism can be specified by whose operation those selected differ from those not selected. He points out that the number of different patterns is also immense in the physical science of statistical mechanics, but in that case the variation of structure from pattern to pattern averages out. The patterns of inorganic systems repeat themselves over and over again ad infinitum, while those of each organism are unique…*

The third principle is holistic memory. *It provides the criterion for choice not expressed in the second principle. That criterion is information stability. The term 'memory' in a generalized sense indicates stability of information in time or, as in the case of heredity, the reproduction of information in an empirical sense, that is, without our knowing the full mechanism of reproduction. The creative selection of the second principle means the organism has many more states to choose from than are actually needed. The third principle says the organism uses this freedom to create a pattern that resembles earlier patterns. Walter borrowed the term 'memory without storage' from the philosopher Henri Bergson…*

Holistic memory requires a fourth principle, operative symbolism, *to indicate that a material carrier of information is needed, namely DNA, but this acts as a releaser or operative symbol for the capacity of the whole organism to reconstruct a complete message that characterizes the adult of the next generation… In other words, operative symbolism is not necessary to the development of the postulational system of he first three principles that can do away with the conceptual difficulties and internal contradictions that always appear in any purely mechanistic interpretation of organic life. The informational system of organisms is therefore postulated to be dualistic; on one level it is mechanistic in the operation of the genetic code; on the other level it is holistic, involving the entire cell or organism."*

Notes

Originally published as Elsasser, W. M. (1981). “A form of logic suited for biology,” in R. Rosen (ed.),*Progress in Theoretical Biology*, Volume 6, ISBN 0125431066, Academic Press, pp. 23-62. Reproduced by kind permission of Elsevier. We are very grateful to Aloisius Louie and Linda Henderson for providing high quality digital scans of the original article. The original article can be downloaded from here.

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