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Perspectives

The Complexity of Life

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"Verily at the first Chaos came to be, but next wide-bosomed Earth, the ever-sure foundations of all the deathless ones who hold the peaks of snowy Olympus, and dim Tartarus in the depth of the wide-pathed Earth, and Eros, fairest among the deathless gods, who unnerves the limbs and overcomes the mind and wise counsels of all gods and all men within them. From Chaos came forth Erebus and black Night; but of Night were born Aether and Day, whom she conceived and bare from union in love with Erebus. And Earth first bare starry Heaven, equal to herself, to cover her on every side, and to be an ever-sure abiding-place for the blessed gods." — Hesiod, from the Theogony, Part 2, translated by H.G. Evelyn-White

HE CLASSICAL UNIVERSE is made up brick by brick, starting in the void and culminating with the earth: from the emptiness of night that gave rise to day, to the day that produces the outward order of the heavens, and finally to life upon the ground. The *Theogony* is a story describing the origins of energy and matter and information in the form of life. The *Theogony* exemplifies humanity's great surprise that the universe should have emerged from chaos, that emptiness has not reigned eternal, and that the earth should be hospitable and supportive of multiform sentience. After almost three millennia our concerns are essentially the same as those of this celebrated Greek farmer and poet. In just less than 14 billion years, the universe has generated, from nothing, more than 100 billion galaxies, each of which contains on average 100 billion stars, and around many of these stars a system of planets. In our own Milky Way, tucked away in a local bubble of the Orion-Cygnus arm of the galaxy, 27,000 light years from the galactic center, spins our solar system, home to eight planets – four small and dense, and four large and gaseous. On one of these planets, the third nearest the sun, we find life. To the best of our knowledge, it is the only planet in our solar system supporting adaptive matter.

From physical law we can derive essential properties of the sun, the elements, and the planets. The incredible machinery of the theories of gravity, quantum mechanics, and the standard model

Inorganic chemistry is essentially silent on the topic of biology. We do not exist. The theory of everything is a theory of everything except of those things that theorize."



David Krakauer

give us significant insights into the observable structure in the universe. Optimistically, we can even deduce simple molecules from inorganic chemistry. And then the theory machine stops. Physics runs out of gas. Chemistry dries up. From the perspective of physics, our own solar system or galaxy are not in any way different from those anywhere else in the universe. Inorganic chemistry is essentially silent on the topic of biology. We do not exist. The theory of everything is a theory of everything except of those things that theorize.





The projects described in this issue of the *Bulletin* are all efforts to grapple with some of the key ideas and concepts required to understand living systems, with an emphasis on evolution, both biological and cultural. We ask how, over long stretches of time, successively more effective mechanisms for storing and processing information have been adaptively engineered, and how these biological computing systems are used to predict, model, and control relevant states of noisy and living environments. We consider complexity through the lens of information processing, we seek to quantify how information is encoded in living systems (genomes and brains), and we suggest estimates for upper bounds in adaptive information capacity. Some of the concepts relevant to understanding biological complexity include hierarchy, individuality, criticality, information/uncertainty, computation, and sociality.

Stanislaw Lem in his science fiction *chef-d'œuvre Solaris* (1961) considers a planet swaddled by an inscrutable ocean capable of astonishing acts of reasoning. So vastly more intelligent and powerful is the Ocean to the human explorers and scientists (Solarists) who dedicate their lives to its analysis and explication that humanity is forced to resign itself to ignorance over its ultimate mechanisms and motives. I have often wondered whether Solaris is not a metaphor for life on earth, where the methods of the Solarists are the traditional



methods of science. Solaris is a huge interconnected system of energy and information flows that defy traditional methods of reduction. Perhaps Solaris is waiting on complexity science: information theory, scaling, network theory, evolutionary dynamics, and computation. Perhaps we only stand a chance of understanding complex life when we approach it through the sciences of complexity – in which case, consider this issue of the *Bulletin* a temporary visa granting access to all of those restless explorers intent on the understanding of our terrestrial Solaris. **Cronus mutilates his father**, Uranus, at the behest of his mother, Gaia, in this scene from Greek mythology featured in Hesiod's *Theogony*.