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The Constraints of Chance (Jan 1996, essay, Scientific American)

It has become fashionable for biologists to emphasize the role of contingency in the origin and evolution of life on the earth, including the advent of humankind and the development of mind. Those momentous events are said to be the products of highly improbable combinations of chance occurrences. As the late Jacques Monod wrote in his 1970 best-seller Chance and Necessity, "the universe was not pregnant with life, nor the biosphere with man." Often presented as established fact, such affirmations are seen as driving the final nail into the coffin of whatever illusion we still entertain about the human condition and its significance in the universe. When examined critically, however, the science behind this view emerges as less conclusive than is commonly believed.

The thesis that the origin of life was highly improbable is demonstrably false. Life did not arise in a single shot. Only a miracle could have done so. If life appeared by way of scientifically explainable events, it must have followed a very long succession of chemical steps leading to the formation of increasingly complex molecular assemblages. Being chemical, those steps must have been strongly deterministic and reproducible, imposed by the physical and chemical conditions under which they took place.

The involvement of many steps reinforces their deterministic character. Single events of very low probability readily take place, but a connected string of such events does not. Bridge hands are being dealt all the time, each with a probability of one in 5 × 1028. But the same hand is essentially never dealt twice, let alone many times, in succession. Given the nature of matter and given the conditions that existed on the earth four billion years ago, life was bound to arise in a form not very different, at least in its basic molecular properties, from its present form.

What now of the probability of evolution producing conscious beings? Here the proponents of contingency seem to stand on safe Darwinian ground. Hardly any biologist today doubts that every evolutionary step starts with a fortuitous heritable change, the outcome of which is then tested by natural selection. The obvious implication is that chance governs the directions of evolution. This is the majority opinion— justified, but in need of qualification.

Chance does not exclude inevitability. Of critical importance are the constraints within which chance operates. One is the number of options. There are only two possibilities when a coin is flipped, six when a die is cast, 36 when a roulette wheel is spun and 5 × 10 28 when a hand of bridge is dealt. The number may be large, but it is always finite. So it is with possible mutations. Their number is not only limited, it is not even extremely large, relatively speaking. This point is readily corroborated by experience.

Antibiotic-resistant bacteria, chloroquine-resistant malarial parasites, DDT-resistant mosquitoes and herbicide-resistant weeds all have appeared in the course of a few decades—not thanks to fluke (casualidad) mutations but because the spread of the drugs has suddenly given banal mutations an opportunity to prove beneficial and be selected. If wide-ranging changes of this kind can take place in such a short span, evolutionary times of millions of years are likely to allow for almost every useful eventuality. Contrary to a widespread notion, evolution does not so much follow the vagaries (caprichos) of chance mutations—although this may occasionally happen— as do mutations wait, so to speak, for an opportunity to affect the course of evolution.

In multicellular organisms, existing body plans impose additional constraints on evolution. Effective mutations are restricted to the small number of genes that control the development of an organism—such as homeotic genes—and must be such as to modify the developmental blueprint in a manner conducive to evolutionary success or at least compatible with it. Most of the changes that meet these conditions do not alter the basic body plan. They characterize what I call "horizontal" evolution and lead to biodiversity. There are probably more than one million species of insects, but all are insects. It is in this kind of diversification that contingency plays its leading role, mostly in the form of environmental conditions that happen to provide some mutation with a selective advantage.

Much fewer, because far more constrained, are the changes that significantly increase the complexity of body plans ("vertical" evolution). The constraints no doubt leave room for developments that failed to happen on the earth but could happen elsewhere, and vice versa. But some directions could be compelling. The emergence of thinking beings, for instance, appears much less improbable than is often intimated. Once neurons emerged and started interconnecting, life progressed toward the formation of increasingly complex networks, no doubt furthered by the associated selective advantages. Six million years ago a chimpanzee's brain represented the apex of this evolutionary progression. Three million years ago it was Lucy's. Today it is the human mind. What it will be six million years hence —or what has already materialized elsewhere— is anybody's guess.

Life and mind appear as cosmic imperatives, written into the fabric of the universe. Given the opportunity, matter must give rise to life, and life to mind. Conditions on our planet provided this opportunity. The prevalent opinion among cosmologists is that such conditions may prevail on many other sites in the universe. If so, and if the views defended in this essay are correct, there must be many other living planets, at least a fraction of which have evolved or shall evolve toward the formation of conscious beings —some perhaps more advanced than we.

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