Originating Life: Six big questions

Tutorial by Holmes Rolston, February 21, 2003[1]

To learn about the origin of life, Holmes Rolston III said, look beyond the beginnings of matter and energy and focus on the development of biological information. The Colorado State University philosophy professor, whose work on environmental ethics earned him the 2003 John Templeton Foundation Prize for Progress Toward Research or Discoveries about Spiritual Realities, spoke to a group of about 25 scientists, theologians, philosophers, and historians gathered for a NASA and Templeton Foundation funded workshop on the Origin of Life, hosted by the Program of Dialogue on Science, Ethics, and Religion of the American Association for the Advancement of Science. His presentation highlighted not what science knows about the origin of life, but the questions it has not been able to answer.

He started by quoting several eminent scientists, including George C. Williams, Klaus Dose, and John Maynard Smith, who have expressed doubts (that Rolston shares) about most scientists' grasp of fundamental questions of matter, energy, and biological information. "It's fashionable to say that matter and energy are self-organizing," said Rolston. "But in this self-organizing something generates novel biological information." To illustrate this point, Rolston outlined the development of multicellular organisms.

A gene is a packet of information. Genes group themselves into sequences that organize and concentrate in the nuclei of eukaryotic cells (cells with organized, differentiated internal structures). Meiotic division of the cells redistributes the genetic information, which, over the course of several generations, allows cells to take on specialized functions. Complex multicellular organisms can then develop. Information seems to generate more information, Rolston said. Unlike matter and energy, which change form but do not come into being or pass out of being, "We can say that information appears ex nihilo [from nowhere] because there was no information before."

Rolston then turned to the question of life's contingency. Is the formation of life contingent, appearing only in the rare instances where the environment fosters it? Or does the universe produce life inevitably and by necessity? "Some molecular biologists think that it's a pretty probable thing written into the chemistry," said Rolston, quoting from the book Vital Dust by the Nobel Prize-winning biochemist Christian de Duve: "Life is bound to arise under the prevailing conditions, and it will arise similarly wherever and whenever the same conditions obtain. There is hardly any room for `lucky accidents' in the gradual multistep process whereby life originated. ... I view this universe [as] made in such a way as to generate life and mind, bound to give birth to thinking beings."

Nobel laureate scientists George Wald, Melvin Calvin, and Manfred Eigen have given voice to similar thoughts, as has the prominent scientist and writer, Stuart Kauffman.

[1] Refer to CD for accompanying presentation slides

Rolston displayed graphs showing a remarkable increase in the number of land and marine species over time, despite occasional catastrophic extinctions. "The question to ask is: Does it look like what has happened has had a tendency, or a direction? If so, would it happen again?" Rolston Leigh Van Valen, a theoretical biologist at the University of Chicago: Play the tape of history again. If played just once more, the differences would strike us first. "Play the tape a few more times, though. We see similar melodic elements appearing in each, and the overall structure may be quite similar.

...When we take a broader view, the role of contingency diminishes. Look at the tape as a whole. It resembles in some ways a symphony, although its orchestration is internal and caused largely by the interactions of many melodic strands."

Some scientists, however, insist that the development of complex life forms is not an inevitable result of any general law, even though it has managed to happen. Stephen Jay Gould said, "We are the accidental result of an unplanned process ... the fragile result of an enormous concatenation of improbabilities, not the predictable product of any definite process." Perhaps hair will grow whiter in cold environments, but there are no perfecting principles. "Almost every interesting event of life's history falls into the realm of contingency."

Michael Ruse argues that "progressivism," the notion that evolutionary history tends to become more complex over time, is really a cultural belief originating in Britain that should not be confused with science; yet it clearly colors the work of some prominent evolutionary theorists. In this view, "evolution functions as an ideology, a secular religion: that of progress," said Rolston. Michael Ruse makes this point sharply: "Evolution is going nowhere, and rather slowly at that."

Understanding the origin of life involves thinking about possibilities as well as about what actually happened. How do we think about the presence of possibilities first in the astronomical and later in the biological worlds? Does the number of possibilities, which Rolston calls "possibility space," remain constant over time, or do possibilities increase? Might we have a world of infinite possibilities from the Big Bang onward? Or instead do new possibilities appear from time to time during the course of evolutionary history?

Possibilities, both logical and empirical, take many forms. They are restricted by the physical and historical limitations of our universe. Something that might have been logically or empirically possible at one point in history may be eliminated by subsequent events. But new historical possibilities may open up instead. In that sense, Rolston said, we must ask about the element of unpredictability in the universe.

For example, creatures with silica exoskeletons (shells that support and protect internal organs) were extant for 4 billion years, but then arthropods (joint-legged crustaceans) with chiton exoskeletons appeared. Organisms that came later developed endoskeletons (interior bones) that were composed of calcium, a different material. "These seem to be twists and turns that represent a kind of novelty that we may not be able to predict," Rolston said. Despite Melvin Calvin's belief that biological life was a "logical necessity" of the physical chemistry or Christian de Duve's belief that life was inevitable, the development of eukaryotes (cells with nuclei and DNA) might not inevitably and necessarily lead to the development of, for example, trilobites. "If you get trilobites, is it a sure or probable thing that you are going to get primates?"

It might not be possible to connect the ultimate outcome with the initial conditions, Rolston insisted, quoting Karl Popper, a philosopher of science: who concluded that science discovers "a world of propensities," open to historical innovation, the possibility space ever enlarging. "In our real changing world, the situation and, with it, the possibilities, and thus the propensities, change all the time...This view of propensities allows us to see in a new light the processes that constitute our world: the world process. The world is no longer a causal machine--it can now be seen as a world of propensities, as an unfolding process of realizing possibilities and of unfolding new possibilities. ... New possibilities are created, possibilities that previously simply did not exist. ... Especially in the evolution of biochemistry, it is widely appreciated that every new compound creates new possibilities for further new compounds to synthesize: possibilities which previously did not exist. The possibility space...is growing...Our world of propensities is inherently creative."

Rolston believes that possibility space is growing. An iron atom that perhaps came to earth on a meteorite could surely make its way into the fruit of a tomato plant; we can then eat it, causing it to enter the hemoglobin in our bodies, and the brains with which we think. Does an iron atom always and inevitably have those possibilities? "I think the answer is no," said Rolston, "those possibilities are not in the iron atom as such but they are in the iron atom plus information that is genetically generated, where no such information was present before."

The concept of co-option, Rolston said, helps describe how new, unforeseen possibilities develop. No bones ever originated, for example, solely for the purpose of amplifying sound. But at some point a bone inside a swimming animal was co-opted (put to a different use) to become a sound amplifier. Pressure cells on the side of the animal responded to the amplified sound vibrations by developing waving fingerlike structures called stereocilia, which changed the sound vibrations into microscopic electric currents and channeled them to other cellular structures that helped the animal interpret the sounds.

All this happened because an organism needed better information, causing a pressure cell that the animal was originally using to swim better to be co-opted from its original use. The results of this process are profound: communication among animals developed, and later, human language and the passage of cultural ideas from mind to mind. "Previously disconnected parts of the organism were working along different pathways, when they were co-opted and put together to serve a new and novel function."

Rolston wondered about critical turning points in the history of life, involving miochondria and chloroplasts. Once-independent organisms fused into other, larger cells and became mitochondria, which became the powerhouses for life. There appears ("emerges") a new kind of system--one where the organism has highly efficient and specialized power modules (the mitochondria)--something not possible to either of the precedents before they interacted, criss-crossed, synthesized and transformed each other. The "information" about how to do this was not present before in the preceding organisms, but now there has appeared new "information" (coded in the revised DNA in the nucleus and the residual DNA in the mitochondrion) that makes this new, high-powered form of life possible.

Another critical symbiosis brought free-living chloroplasts into the plant cell, again producing the energy vital for all life.
Was all that resulted all along in the possibility spaces of all the predecessor organisms? Maybe some of the possibility was within one organism, some within the other? Isn't it equally plausible to believe that new possibility space appeared with the co-option of the mitochondria and chloroplast predecessor organisms to novel functions? Some achievements that are genuinely new pop up. These are based on the precedents, but there is novelty not present in either of the precedents. What emerged required the precedents, but the presence of the prior organisms, which became precedents, did not require or determine these results.

Biologists, a century back, used to call such events "saltations." Physicists, pressed for words from their discipline, might call it a "quantum leap." Maybe we need a new term: "cybernetic leap." Biologists inclined toward chance may call this "tinkering." Biologists impressed with the results will call it evolutionary "exploring." One needs a metaphysics for such co-option because there appear new ontological levels, both actual and possible (sight where before was only heat stress protection; language where before was only skin pressure sensibility; sight and language opening up the possibility of writing/reading). Co-option is the key to historical creativity.

Another intriguing characteristic of life is its defiance of entropy. The entropy problem can be summed up as follows: Organisms pump out disorder. "The world is taking you apart, generally," Rolston said. "That's why you need metabolism and replication. It's a kind of fight that has to be maintained." Life, however, is atypical: Life a local countercurrent to entropy, an ongoing process of organizing and ordering. For life to start and continue, some kind of "push-up, lock-up" effect is required. He compared the course of life to an old-fashioned hydraulic ram, which pumps water uphill using the downstream force of the water. "Life in that sense has to run uphill against entropy. We might know how DNA makes an organism, and how an organism makes DNA, but the problem is how the loop starts."

Finally, many physicists consider the conditions created by the Big Bang to be fine-tuned to produce stars, which in 10 billion years generated carbon and other elements needed to support the beginning of life. This idea of fine-tuning is an important tenet of the "anthropic principle" (Rolston would rename it the "biophilic principle"), which holds that a combination of cosmic coincidences produced a universe that is uniquely suited for the development of life. "As the chemicals are made, the universe looks sort of friendly toward the possibility of life." But, he added, the processes of evolution that Darwinian theorists describe are blind and random and involve the survival of the fittest: "It doesn't look all that user-friendly."

Over the millennia, however, more life clearly comes out of less. There appears to be a self-actualizing or self-transcending tendency in the biological world, an opening of possibility space. "Biology is more pushy than fine-tuned about life," Rolston said. "Earth has proved to be a wonderland." But many questions about how life, biodiversity, and biocomplexity came into being have yet to be answered by science.

By Nancy Ellen Roth, Science Writer