eventually say technology as technology received its status only in the 1930s.

For our purposes, chapter 13, "Conclusion: Technology as Keyword in the 1960s and Beyond," is perhaps the most relevant. Schatzberg traces the modern senses of technology in the second half of the last century: technology as the industrial arts, technology as applied science, and technology as techniques. Subjects such as technology as innovation, technology and social change, and critiques of technology in the 1960s are briefly explored. Technology taken as an oppressive system of technical knowledge in Jacques Ellul, Herbert Marcuse, and Lewis Mumford is followed by a discussion of "contested technology" by Ralph Nader, Rachel Carson, Barry Commoner, and E. E. Schumacher.

What I found most interesting and valuable in this book, in addition to all the nuanced historical insights, is Schatzberg's effort to speak to the nature and future of technology. He ends with a two-page manifesto entitled "Rehabilitating Technology" that begins as follows:

> This book is not a neutral work of scholarship but rather an intervention in the present, a first step in rehabilitating technology as a concept for history and social theory, with an eventual goal of shaping technologies toward more human ends. (p. 235)

Schatzberg wants to rehabilitate technology from scholars who tend to reduce technology to instrumental reason or from determinists who view technology as being driven by its own ends. He wishes to give a cultural face to technology: one that is driven by human agency and choice, interested in reestablishing cultural links between the arts (in the old sense) and technology, open to reclaiming the crafts as an essential element of technology, and careful of the nature of application of science and technology.

Cultural values couched in human agency ride high: technology as the "creative expression of human values and strivings, in all their contradictory complexity" (p. 232). We need, Schatzberg argues, to change our view of technology, to think ethically, and to see it as an expression of human values. But, unfortunately, there is little mention of any normative considerations either in the evaluation of technology or in the design process integral to technology—something *Responsible Technology* attempted to articulate in its halting fashion and discussion of normativity in the design process. That would perhaps have meant writing another book.

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Letters

A Greater Degree of Discontinuity

"Rethinking Abiogenesis: Part 1, Continuity of Life through Time," (*PSCF* 72, no 1 [2020]: 25–35) by Emily Boring, J. B. Stump, and Stephen Freeland provides a fascinating and thoughtful view of the nature of evolutionary continuity, especially as related to the origin of life. There seems to be no question that evolutionary continuity (as Darwin originally proposed) is profoundly important and a generally accurate concept for most of the history of life. The authors correctly argue that when probing the details of the emergence of life, ignoring specific cases of continuity (as in the example they give of the appearance of the canonical set of amino acids) runs the risk of missing an opportunity for advancing our knowledge.

The same could be said, however, about ignoring those instances where an apparent discontinuity should lead us to a more in-depth exploration. We know that there are clear examples of discontinuity throughout evolutionary history that have been accepted by the majority of biologists.[1] These include such events as the origin of eukaryotes by endosymbiosis[2] and the origin of vertebrates, which appear to have involved at least one whole-genome duplication event.[3] Gould and Eldredge's theory of punctuated equilibrium is supported by a good deal of evidence for discontinuities in the evolutionary record.[4]

The authors argue that because of the continuity principle, the unequivocal identification of any particular event as the beginning of life is impossible. Extending the general evolutionary paradigm to the big bang, the authors state that "natural selection is not limited to acting only on what we take to be alive" (p. 30). That could be true, but natural selection is not the whole story of evolution. They go on to say that anything that leaves copies of itself can evolve if some of those copies are able to produce more copies than others. While that seems like a logical statement, it ignores a critical feature of biological evolution.

Stated simply, it is not enough to make copies of oneself (with variations). The copies made must be accurate enough so that whatever features natural selection acts upon are copied correctly through generations. If the copying mechanism is 100% perfect, there will be no variations and no possibility for evolution. But if the copies are only 50% accurate, and only half the features of the parent(s) are retained in the offspring, it is quite likely that any phenotypic features recognized by natural selection to be worth selecting will be lost, and evolution of the fittest will not happen. And if the replication accuracy is poor enough, the new cell or organism might not even survive ("error catastrophe").[5]

How accurate must the copying mechanism be? In all modern life, the answer is roughly 99.9999%. In order to avoid an error catastrophe, the maximum replication error rate for an informational molecule such as DNA or RNA is equal to the inverse of the molecule length.[6] As the authors mention, an RNA ribozyme that can serve both as an informational storage and catalytic molecule must be at least several hundred nucleotides. But even a very small such molecule of, say, 50 nucleotides means that the replication error could not exceed 2%; that is, a 98% accuracy is required. This is far beyond the capacity of any such early replicator as far as we know at present.

While we can imagine a form of life that might not evolve yet still carries out various metabolic and even replication functions,[7] many biologists assume that "life" began when the process of biological evolution became possible. Some textbooks even use this as a definition for life.

The evolutionary process requires pretty much everything we see in the central dogma, including DNA as the informational storage molecule with highly accurate replication, transcription, and translational machineries.[8] Once we begin to have functional biological evolution (with high replication fidelity), we have reached a cell indistinguishable from the Last Universal Common Ancestor (LUCA). We have no good theories as to how life could have evolved before biological evolution, as we know it, was possible.

I am not arguing against the authors' overarching view of continuity in nature and the difficulty, if not impossibility, of determining any particular point at which a new feature of the universe began. For most purposes, continuity is a coherent and useful way to approach the reality of biology and all of nature, both scientifically and theologically. My goal is to stress the aspects of those natural processes, such as the origin of life, that show a greater degree of discontinuity than is seen, for example, in the evolution of life after LUCA. This includes the problem of the evolution of replication fidelity.[9] More attention on these questions is likely to produce interesting and perhaps even revolutionary new information on the mechanisms by which God's creation has come to be the marvel we know.

Notes

[1]Eugene V. Koonin, "The Biological Big Bang Model for the Major Transitions in Evolution," *Biology Direct* 2 (2007): 21, https://doi.org/10.1186/1745-6150-2-21; Walter Fontana and Peter Schuster, "Continuity in Evolution: On the Nature of Transitions," *Science* 280, no. 5368 (1998):1451–55, https://doi.org/10.1126/science.280.5368.1451; and Luciana Raggi, Jeffrey L. Bada, and Antonio Lazcano, "On the Lack of Evolutionary Continuity between Prebiotic Peptides and Extant Enzymes," *Physical Chemistry Chemical Physics* 18, no. 30 (2016): 20028–32.

[2]Lynn Margulis, "Archaeal-eubacterial Mergers in the Origin of Eukarya: Phylogenetic Classification of Life," *Proceedings of the National Academy of Sciences of the United States of America* 93, no. 3 (1996): 1071–76, https://doi.org/10.1073/pnas.93.3.1071; and William F. Martin, Sriram Garg, and Verena Zimorski, "Endosymbiotic Theories for Eukaryote Origin," *Philosophical Transactions of the Royal Society B Biological Sciences* 370, no. 1678 (2015), https://doi.org/10.1098/rstb.2014.0330.

[3]Jeremy E. Coate and Jeff J. Doyle, "Divergent Evolutionary Fates of Major Photosynthetic Gene Networks Following Gene and Whole Genome Duplications," *Plant Signaling and Behavior* 6, no. 4 (2011): 594–97, and Paramvir Dehal and Jeffrey L. Boore, "Two Rounds of Whole Genome Duplication in the Ancestral Vertebrate," *PLoS Biology* 3, no. 10 (2005): e314.

[4]Stephen Jay Gould and Niles Eldredge, "Punctuated Equilibrium Comes of Age," *Nature* 366 (1993): 223–27, https://doi.org/10.1038/366223a0.

[5]Manfred Eigen, "Error Catastrophe and Antiviral Strategy," *Proceedings of the National Academy of Sciences of the United States of America* 99, no. 21 (2002): 13374–76, https://doi.org/10.1073/pnas.212514799.

[6]Jack W. Szostak, "The Eightfold Path to Non-Enzymatic RNA Replication," *Journal of Systems Chemistry* 3, no. 1 (2012): 2, http://www.jsystchem.com/content/3/1/2; and Martin A. Nowak, *Evolutionary Dynamics: Exploring the Equations of Life* (Cambridge, MA: Belknap Press, 2006).

[7]Sy Garte, "Teleology and the Origin of Evolution," *Perspectives on Science and Christian Faith* 69, no. 1 (2017): 42–50.

[8]Ibid.

[9]Sy Garte, "The Continuity Principle and the Evolution of Replication Fidelity," manuscript submitted, 2020.

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Key Speculation

The major unsolved problem of life on Earth has been how life emerged from nonliving organic material. This problem has confounded scientists starting with Alexander Oparin in 1924, John Haldane in 1929, through the carefully controlled laboratory tests in 1953 by Harold Urey and Stanley Miller, and has continued to occupy biochemists, biophysicists, and synthetic organic chemists from 1953 until today, with no apparent success. In addition, *all these efforts to date have involved intelligent beings, i.e., human interaction, under carefully controlled experiments*.

One of the most recent efforts has been by Nobel Laureate Jack Szostak, who obtained microcapsule prebiotic samples in his laboratory. In "Rethinking Abiogenesis: Part 1, Continuity of Life through Time," (*PSCF* 72, no 1 [2020]: 25–35) by Emily Boring, J. B. Stump, and Stephen Freeland, I do not see any reference to Szostak.

Because the authors are committed to evolutionary creation, it is no surprise that their key speculation is summarized in paragraph 4, under the section entitled "Why Does the Perspective of Continuity Matter?" Given their presuppositions, they seek to avoid any and all discontinuities, even though, as C.S. Lewis aptly stated regarding biblical miracles, God is the author of