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What Was Life? Answers from Three Limit Biologies

Stefan Helmreich

“What was life? No one knew.”

—THOMAS MANN, *The Magic Mountain*

What is life? A gathering consensus in anthropology, science studies, and philosophy of biology suggests that the theoretical object of biology, “life,” is today in transformation, if not dissolution. Proliferating reproductive technologies, along with genomic reshufflings of biomatter in such practices as cloning, have unwound the facts of life.¹ Biotechnology, bio-

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1. See Marilyn Strathern, *Reproducing the Future: Anthropology, Kinship, and the New Reproductive Technologies* (Manchester, 1992); *Conceiving the New World Order: The Global Politics of Reproduction*, ed. Faye D. Ginsburg and Rayna Rapp (Berkeley, 1995); Valerie Hartouni, *Cultural Conceptions: On Reproductive Technologies and the Remaking of Life* (Minneapolis, 1997); *Cyborg Babies: From Techno-sex to Techno-Tots*, ed. Robbie Davis-Floyd and Joseph Dumit (New York, 1998); *Reproducing Reproduction: Kinship, Power, and Technological Innovation*, ed. Sarah Franklin and Helena Ragoné (Philadelphia, 1998); Susan

diversity, bioprospecting, biosecurity, biotransfer, and molecularized biopolitics draw novel lines of property and protection around organisms and their elements.² From cultural theorists and historians of science we learn

Martha Kahn, *Reproducing Jews: A Cultural Account of Assisted Conception in Israel* (Durham, N.C., 2000); Gay Becker, *The Elusive Embryo: How Women and Men Approach New Reproductive Technologies* (Berkeley, 2000); Linda L. Layne, *Motherhood Lost: A Feminist Account of Pregnancy Loss in America* (New York, 2002); Marcia C. Inhorn, *Local Babies, Global Science: Gender, Religion, and In Vitro Fertilization in Egypt* (New York, 2003); Heather Paxson, *Making Modern Mothers: Ethics and Family Planning in Urban Greece* (Berkeley, 2004); Charis Thompson, *Making Parents: The Ontological Choreography of Reproductive Technologies* (Cambridge, Mass., 2005); Susan Merrill Squier, *Liminal Lives: Imagining the Human at the Frontiers of Biomedicine* (Durham, N.C., 2004); Franklin and Celia Roberts, *Born and Made: An Ethnography of Preimplantation Genetic Diagnosis* (Princeton, N.J., 2006); Lisa Jean Moore, *Sperm Counts: Overcome by Man's Most Precious Fluid* (New York, 2007); and Lynn M. Morgan, *Ions of Life: A Cultural History of Human Embryos* (Berkeley, 2009).

2. See Donna J. Haraway, *Modest_Witness@Second_Millennium.FemaleMan©_Meets_OncoMouse™: Feminism and Technoscience* (New York, 1997); *Changing Life: Genomes, Ecologies, Bodies, Commodities*, ed. Peter J. Taylor, Saul E. Halfon, and Paul N. Edwards (Minneapolis, 1997); Paul Rabinow, *French DNA: Trouble in Purgatory* (Chicago, 1999); *Biotechnology and Culture: Bodies, Anxieties, Ethics*, ed. Paul E. Brodwin (Bloomington, Ind., 2001); Adriana Petryna, *Life Exposed: Biological Citizens after Chernobyl* (Princeton, N.J., 2002); Margaret Lock, *Twice Dead: Organ Transplants and the Reinvention of Death* (Berkeley, 2002); Cori Hayden, *When Nature Goes Public: The Making and Unmaking of Bioprospecting in Mexico* (Princeton, N.J., 2003); *Genetic Nature/Culture: Anthropology and Science beyond the Two-Culture Divide*, ed. Alan Goodman, Deborah Heath, and M. Susan Lindee (Berkeley, 2003); *Remaking Life and Death: Toward an Anthropology of the Biosciences*, ed. Franklin and Lock (Santa Fe, 2003); Sheila Jasanoff, *Designs on Nature: Science and Democracy in Europe and the United States* (Princeton, N.J., 2005); Jenny Reardon, *Race to the Finish: Identity and Governance in an Age of Genomics* (Princeton, N.J., 2005); João Beihl, *Vita: Life in a Zone of Social Abandonment* (Berkeley, 2005); Catherine Waldby and Robert Mitchell, *Tissue Economies: Blood, Organs, and Cell Lines in Late Capitalism* (Durham, N.C., 2006); Celia Lowe, *Wild Profusion: Biodiversity Conservation in an Indonesian Archipelago* (Princeton, N.J., 2006); Leslie A. Sharp, *Strange Harvest: Organ Transplants, Denatured Bodies, and the Transformed Self* (Berkeley, 2006); Kaushik Sunder Rajan, *Biocapital: The Constitution of Postgenomic Life* (Durham, N.C., 2006); Nikolas Rose, *The Politics of Life Itself: Biomedicine, Power, and Subjectivity in the Twenty-First Century* (Princeton, N.J., 2006); Gisli Pálsson, *Anthropology and the New Genetics* (Cambridge, 2007); Melinda Cooper, *Life as Surplus: Biotechnology and Capitalism in the Neoliberal Era* (Seattle, 2008); Sandra Bamford, *Biology Unmoored: Melanesian Reflections on Life and Biotechnology* (Berkeley, 2007); *Revisiting Race in a Genomic Age*, ed. Barbara A. Koenig, Sandra Soo-Jin Lee, and Sarah S. Richardson, (New Brunswick, N.J., 2008); Mike Fortun, *Promising Genomics: Iceland and deCODE Genetics in a World of Speculation* (Berkeley, 2008); *Biosocialities, Genetics, and the Social Sciences: Making Biologies and Identities*, ed. Sahra Gibbon and Carlos Novas (Abingdon, 2007); *Tactical Biopolitics: Art, Activism, and*

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that life itself, consolidated as the object of biology around 1800, has morphed as material components of living things—cells and genes—that are rearranged and dispersed, and frozen, amplified, and exchanged within and across laboratories.³ Writers in philosophy, rhetoric, and cultural studies, meanwhile, claim that, as life has become the target of digital simulation and bioinformatic representation, it has become virtual, mediated, and multiple.⁴

All these transformations destabilize any naturalistic or ontological foundation that life forms—embodied bits of vitality like organisms and species—might provide for forms of life—social, symbolic, and pragmatic ways of thinking and acting that organize human communities.⁵ In the

Technoscience, ed. Beatriz de Costa and Kavita Philip (Cambridge, Mass., 2008); Franklin, *Dolly Mixtures: The Remaking of Genealogy* (Durham, N.C., 2007); *Signs of Life: Bio Art and Beyond*, ed. Eduardo Kac (Cambridge, Mass., 2007); *Biosecurity Interventions: Global Health and Security in Question*, ed. Andrew Lakoff and Stephen J. Collier (New York, 2008); Karen-Sue Taussig, *Ordinary Genomes: Science, Citizenship, and Genetic Identities* (Durham, N.C., 2009); *The Handbook of Genetics and Society: Mapping the New Genomic Era*, ed. Paul Atkinson, Peter Glassner, and Lock (London, 2009); Martin G. Weiss, *Bios und Zoë: Die menschliche Natur im Zeitalter ihrer technischen Reproduzierbarkeit* (Frankfurt am Main, 2009); and Robert Mitchell, *Bioart and the Vitality of Media* (Seattle, 2010).

3. See William Coleman, *Biology in the Nineteenth Century: Problems of Form, Function, and Transformation* (New York, 1971); Lynn K. Nyhart, *Biology Takes Form: Animal Morphology and the German Universities, 1800–1900* (Chicago, 1995); Evelyn Fox Keller, *Refiguring Life: Metaphors of Twentieth-Century Biology* (New York, 1995), *The Century of the Gene* (Cambridge, Mass., 2000), and *Making Sense of Life: Explaining Biological Development with Models, Metaphors, and Machines* (Cambridge, Mass., 2003); Lily E. Kay, *Who Wrote the Book of Life?: A History of the Genetic Code* (Stanford, Calif., 2000); Soraya de Chadarevian, *Designs for Life: Molecular Biology after World War II* (Cambridge, 2000); Robert J. Richards, *The Romantic Conception of Life: Science and Philosophy in the Age of Goethe* (Chicago, 2002); Hannah Landecker, *Culturing Life: How Cells Became Technologies* (Cambridge, Mass., 2007); Staffan Müller-Wille and Hans-Jörg Rheinberger, *Heredity Produced: At the Crossroads of Biology, Politics, and Culture 1500–1870* (Cambridge, Mass., 2007); and Phillip Thurtle, *The Emergence of Genetic Rationality* (Seattle, 2008).

4. See Richard Doyle, *On beyond Living: Rhetorical Transformations of the Life Sciences* (Stanford, Calif., 1997) and *Wetwares: Experiments in Postvital Living* (Minneapolis, 2003); Keith Ansell Pearson, *Viroid Life: Perspectives on Nietzsche and the Transhuman Condition* (London, 1997); N. Katherine Hayles, *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics* (Chicago, 1999); Susan Oyama, *The Ontogeny of Information: Developmental Systems and Evolution* (Durham, N.C., 2000); *Data Made Flesh: Embodying Information*, ed. Robert Mitchell and Thurtle (New York, 2004); Eugene Thacker, *Biomedica* (Minneapolis, 2004), *The Global Genome: Biotechnology, Politics, and Culture* (Cambridge, Mass., 2005), and *After Life* (Chicago, 2010); Judith Roof, *The Poetics of DNA* (Minneapolis, 2007); Jackie Stacey, *The Cinematic Life of the Gene* (Durham, N.C., 2010); and Thierry Bardini, *Junkware* (Minneapolis, 2011).

5. Ludwig Wittgenstein defined “form of life” as a frame of reference within which linguistic action becomes meaningful; see Ludwig Wittgenstein, *Philosophical Investigations*, trans. G. E. M. Anscombe (Oxford, 1953). Historians, sociologists, and anthropologists of science have employed the term to speak to scientific, religious, economic, and ethical

language of my own professional guild, anthropology, these changes unsettle the nature so often imagined to ground culture. Life moves out of the domain of the given into the contingent, into quotation marks, appearing not as a thing-in-itself but as something in the making in discourse and practice. "Life" becomes a trace of the scientific and cultural practices that have asked after it, a shadow of the biological and social theories meant to capture it.

In his 1802 *Biologie*, German naturalist Gottfried Reinhold Treviranus asked, "what is life?" a question that, as it has traveled into the present, has admitted various answers.⁶ Erwin Schrödinger's *What Is Life?* (1944) offered that life might issue from a hereditary "code-script," which conception became in subsequent years enlisted into models of DNA and into informatic and cybernetic visions of vitality more generally.⁷ Fifty-one years after Schrödinger, Lynn Margulis and Dorion Sagan offered a less unitary account in their book, *What Is Life?* in which they delivered a distinct answer to the question for each of life's five kingdoms: bacteria, protocists, animals, fungi, and plants—emphasizing neither some underlying logic nor an overarching metaphysics but rather the situated particulars of bacterial, protocist, fungal, plant, and animal embodiment. Life was not something that could be compressed into the logic of a code but was a process ever overcoming itself in an assortment of bodied manifestations.⁸ If Schrödinger's model fit into forms of life calibrated to cold war practices of coding, secrecy, and cryptography, Margulis and Sagan's view speaks to a world in which environmentalism and biodiversity—and their unknown futures—organize contemporary forms of hope and worry.

worldviews. See for example, Steven Shapin and Simon Schaffer, *Leviathan and the Air Pump: Hobbes, Boyle and the Experimental Life* (Princeton, N.J., 1985), and Michael M. J. Fischer, *Emergent Forms of Life and the Anthropological Voice* (Durham, N.C., 2003).

6. Gottfried Reinhold Treviranus, *Biologie, oder, Philosophie der lebenden Natur für Naturforscher und Aerzte* (Göttingen, 1802), p. 16. See also Jean-Baptiste Lamarck, *Recherches sur l'organisation des corps vivants* (Paris, 1802) for a parallel coinage of "biology."

7. See Erwin Schrödinger, "What Is Life?" with "Mind and Matter" and "Autobiographical Sketches" (Cambridge, 1992); Doyle, *On beyond Living*; Keller, *Refiguring Life*; and Kay, *Who Wrote the Book of Life?* See François Jacob, *The Logic of Life: A History of Heredity*, trans. Betty E. Spillman (New York, 1973) for a strong claim about life as program. See *What Is Life? The Next Fifty Years: Speculations on the Future of Biology*, ed. Michael P. Murphy and Luke A. J. O'Neill (Cambridge, 1995), a commemorative reflection on the legacy of Schrödinger. For a contrasting view of life from one of Schrödinger's contemporaries, see J. B. S. Haldane, *What Is Life?* (New York, 1947). This book, from one of Britain's most noted geneticists, argues that a clear view of life will come when biologists "adopt Marxism as a working hypothesis about how men behave and how changes, both in nature and in society, occur" (p. v).

8. See Lynn Margulis and Dorion Sagan, *What Is Life?* (Berkeley, 1995).

But if it is now possible to think of “life” as having a plurality of futures—as a 2007 conference, “Futures of Life,” held in the Department of Science and Technology Studies at Cornell University had it—it is also possible, in the face of a seemingly endless multiplication of forms, to inquire, as did a 2007 conference at Berkeley, “What’s Left of Life?”⁹ That question posed by scholars in the humanities and social sciences asked whether what Michel Foucault in 1966 identified as “life itself,” the epistemic object of biology that Foucault claimed first manifested in the early nineteenth century, still retains its force to organize matters of fact and concern—life forms and forms of life—arrayed around the life sciences.¹⁰ It is a question about limits, a worry about ends. *What was life?*

How has it become possible for scholars in the sciences and humanities to declare the possible end of “life”? How has the following diagnosis, offered by Richard Doyle, become unsurprising?

“Life,” as a scientific object, has been stealthed, rendered indiscernible by our installed systems of representation. No longer the attribute of a sovereign in battle with its evolutionary problem set, the organism its sign of ongoing but always temporary victory, life now resounds not so much within sturdy boundaries as between them.¹¹

9. For a mission statement and program for Cornell’s “Futures of Life: Acquiring and Creating Anticipatory Knowledge,” see “Futures of Life,” Cornell University Department of Science and Technology Studies, www.sts.cornell.edu/Workshop2007/index.htm. On Berkeley’s “What’s Left of Life” conference, see berkeley.edu./news/media/releases/2007/02/08-life.shtml

10. Foucault writes,

Historians want to write histories of biology in the eighteenth century; but they do not realize that biology did not exist then, and that the pattern of knowledge that has been familiar to us for a hundred and fifty years is not valid for a previous period. And that, if biology was unknown, there was a very simple reason for it: that life itself did not exist. All that existed was living beings, which were viewed through a grid of knowledge constituted by *natural history*. [Michel Foucault, *The Order of Things: An Archaeology of the Human Sciences*, trans. pub. (New York, 1970), p. 139]

And see Bruno Latour, “Why Has Critique Run out of Steam? From Matters of Fact to Matters of Concern,” *Critical Inquiry* 30 (Winter 2004): 225–48; recent writers on biotechnology are remixing Foucault something like this: scholars want to write accounts of biology in the early twenty-first century; but they do not realize that biology is transforming and that the pattern of knowledge that has been familiar to us for two hundred years is no longer valid. And that, if biology has been undone, there is a very simple reason for it: life itself has been disassembled and revealed as an effect, not an originary force. All that now exist are living things and their parts, which are viewed through a grid of knowledge constituted by *biotechnology*.

11. Doyle, *Wetwares*, 20.1, [p. 34].

If, as Roberto Esposito has argued in *Critical Inquiry*, biopolitics is an analytic that emerges from the rise of the life sciences, what happens to that analytic as “life” delaminates?¹² Where is life off to?

What *was* life?

The present essay offers some answers, drawing on anthropological fieldwork I have conducted among contemporary biologists. Over the last fifteen years, I have pursued the question of what “life” is becoming in ethnographic work among biologists who think about the limits of life, both as an empirical matter of finding edge cases of vitality and as a matter of framing an encompassing theory of the biological, a theory that can unify all possible cases. In the three scientific communities I have studied, such accounts of life forms are entangled with claims about the sociocultural forms of life proper to a world in which understandings of nature and biology are in revision. Life forms and forms of life inform, transform, and deform one another.

Introducing Three Limit Biologies

In the 1990s, scientists working in the field of Artificial Life (ALife) dedicated themselves to modeling biological systems in computers. Many claimed not just to be simulating life *in silico* but also to be synthesizing new life in cyberspace and in robots. For practitioners, “life” could be decoupled from its carbon instantiations and might one day supersede organic life. In *Silicon Second Nature*, I recounted how scientists in Artificial Life, in dialogue with post- and transhumanists, argued that digital life forms would reveal the informatic logic of evolution, ushering in a science-fiction world in which “life” would become fully technological, a pattern transposable across media.¹³

Around the turn of the millennium a parallel community of biologists chased the limits of life in another context—not cyberspace but ocean space. In *Alien Ocean*, I looked to marine biologists studying microbes in extreme ecologies, like deep-sea hydrothermal vents.¹⁴ These scientists’ encounters with organisms thriving at extremes of temperature, chemistry, and pressure pressed them against the boundaries of assumptions about organic embodiment—with implications for comprehending the limits of life on Earth and for thinking about how political economic forms of life (for example, the consumption of fossil fuels) might encounter or,

12. See Roberto Esposito, “Totalitarianism or Biopolitics? Concerning a Philosophical Interpretation of the Twentieth Century,” *Critical Inquiry* 34 (Summer 2008): 633–44.

13. See Stefan Helmreich, *Silicon Second Nature: Culturing Artificial Life in a Digital World* (Berkeley, 1998).

14. See Helmreich, *Alien Ocean: Anthropological Voyages in Microbial Seas* (Berkeley, 2009).

perhaps, overcome biological limits. Work with microbes that engage in lateral gene transfer to combine genes “within” generations meant that even canonical taxonomy, which names life forms by lines of descent, became unstable, which had implications for apprehending the possible malleability—naturally, technologically—of living things.

Moving from ocean space to outer space, another group of limit biologists—astrobiologists—have been keen to theorize and scout out life at its boundaries. My research among astrobiologists has investigated how these scientists define and discern “biosignatures,” possible signs of extraterrestrial life present either in extraterrestrial rocks that have made their way to Earth or in the remotely read atmospheric profiles of other worlds.¹⁵ Astrobiologists seek traces of possible life elsewhere in the solar system or galaxy and hope such findings can be read back to situate earthly life in a cosmic ecology.

In what follows, I read across my three ethnographic examples to suggest that biologies in which “life” is conceptually stretched to a limit calibrate to uncertainties about what kinds of sociocultural forms of life biology might now anchor. Limit biologies like Artificial Life, extreme marine microbiology, and astrobiology also point to larger instabilities in concepts of nature—organic, earthly, cosmic. Such instabilities can be fruitfully mapped by attending to how scientists of extreme biologies test the limits of *form* in life forms.¹⁶ If, as Treviranus wrote in *Biologie*, the “objects of our research will be the different forms and phenomena of life,” those forms are being deformed by the object and form of biological inquiry.¹⁷ While, *pace* Esposito, there are implications here for the stability of the “bio” in biopolitics, I am equally interested in how biologists think about limits—and I think that the very notion of the *limit*, as an object of study and fascination in biology and in interpretative social science, also requires analytic scrutiny. At this essay’s close, I train attention on limits in order to understand the limits of theory today as it takes form in and transforms both biology and critical inquiry.

15. See Helmreich, “The Signature of Life: Designing the Astrobiological Imagination,” *Grey Room* 23 (Spring 2006): 66–95.

16. For a history of the term *life form* and its connection to questions of form, see Helmreich and Sophia Roosth, “Life Forms: A Keyword Entry,” *Representations*, no. 112 (Fall 2010): 27–53.

17. Quoted in Coleman, *Biology in the Nineteenth Century*, p. 2. Lambert Williams proposes the concept of “difformation” to describe “a *divergence in form from, or lack of conformity with*, some pre-existing standard or reference point, practice, mode of institutionalization, or body of knowledge” (Lambert Williams, “The New Transcendent Subjects: Chaos and Complexity, 1960–2002” [PhD diss., Harvard University, 2010]). One might substitute his “difformation” for my deformation and experiment with the results.

Artificial Life: Life Forms at Limits of Abstraction

The late 1980s and early 1990s saw the rise of Artificial Life, a hybrid of computer science, theoretical biology, and digital gaming devoted to mimicking the logic of biology in the virtual worlds of computer simulation and in the hardware realm of robotics. Named on analogy to Artificial Intelligence, Artificial Life promised to deliver a fully formalized account of life, one that could be instantiated across a variety of platforms, including, most crucially for practitioners, computational media.¹⁸ My 1990s fieldwork among Artificial Life scientists was centered at the Santa Fe Institute dedicated to the sciences of complexity, where researchers claimed that life would be “a property of the organization of matter, rather than a property of matter itself.”¹⁹ Some found this claim so persuasive that they held that life forms could exist in the digital medium of cyberspace; they hoped the creation of such life could expand biology’s purview to include not just *life-as-we-know-it* but also *life-as-it-could-be*—life as it might exist in other materials or elsewhere in the universe. On the initiate’s view, Artificial Life’s extreme abstraction leverages biology into the realm of universal science, like physics, with a formalism applicable anywhere in the cosmos.

Chris Langton characterized the ethos behind Artificial Life as animated by “the attempt to abstract the logical form of life in different material forms.”²⁰ This definition of life holds that formal and material properties can be partitioned and that what matters is form. What was *form* for Artificial Life scientists? Two things: information and performance.

18. See *Artificial Life*, ed. Christopher G. Langton (Redwood City, Calif., 1989). For secondary literature from the humanities and social sciences, see Claus Emmeche, *The Garden in the Machine: The Emerging Science of Artificial Life* (Princeton, N.J., 1991); Sherry Turkle, *Life on the Screen: Identity in the Age of the Internet* (New York, 1995); Lars Risan, “Artificial Life, A Technoscience Leaving Modernity? An Anthropology of Subjects and Objects” (PhD diss., University of Oslo, 1996); Doyle, *On beyond Living, Wetwares*; Helmreich, *Silicon Second Nature*; Alison Adam, *Artificial Knowing: Gender and the Thinking Machine* (London, 1998); Hayles, *How We Became Posthuman*; Sarah Kember, *Cyberfeminism and Artificial Life* (London, 2003); Christopher Kelty and Landecker, “A Theory of Animation: Cells, L-systems, and Film,” *Grey Room* 17 (Fall 2004): 30–63; Mitchell Whitelaw, *Metacreation: Art and Artificial Life* (Cambridge, Mass., 2004); *Genesis Redux: Essays in the History and Philosophy of Artificial Life*, ed. Jessica Riskin (Chicago, 2007); John Johnston, *The Allure of Machinic Life: Cybernetics, Artificial Life, and the New AI* (Cambridge, Mass., 2008); and Robert M. Geraci, *Apocalyptic AI: Visions of Heaven in Robotics, Artificial Intelligence, and Virtual Reality* (Oxford, 2010).

19. Kevin Kelly and Langton, “Toward Artificial Life—Entries in the First Artificial Life 4-H Show,” *Whole Earth Review* 58 (Spring 1988): 74.

20. Kelly, “Designing Perpetual Novelty: Selected Notes from the Second Artificial Life Conference,” in *Doing Science: The Reality Club*, ed. John Brockman (New York, 1991), p. 1.

Information

Artificial Life founded its reputation on computational models of evolutionary dynamics. One of the most popular models during my fieldwork was Tom Ray's *Tierra*, a system in which assembly-language programs resident in random-access memory (RAM) self-replicate based on how efficiently they make use of central processing unit (CPU) time and memory space. Ray described these programs as "digital organisms" and characterized *Tierra* as a "universe" writ in "the chemistry of bits and bytes" within which only the fittest survive (fig. 1). For Ray, trained as a topical ecologist and self-taught as a programmer, *Tierra* is not so much a *model* of evolution as it is "an *instantiation* of evolution by natural selection in the computational medium." "Digital life," Ray writes, "exists in a logical, not material, informational universe."²¹ Ray understands life to be a process of information replication and, like many of his Artificial Life colleagues, interprets genetic code on an analogy to computer code; in fact, the analogy is almost as close as identity. "The 'body' of a digital organism," he urges, "is the information pattern in memory that constitutes its machine language program."²²

The idea that genes are informatic instructions for making organisms emerges from a long Western metaphysical tradition of separating form from matter, of assuming that ontogeny is the playing out of a developmental "program" and that, as Susan Oyama notes, "form, or its modern agent, information, exists before the interactions in which it appears."²³ If one wanted to offer a *longue durée* account, one might hear in Ray's digital ecologies—originating from the action of an "ancestor" "seed program" "inoculated" into a "computational medium"—echoes of an Aristotelian vision of form: a spiritual (often masculinized) force that informs the material (often feminized) world.²⁴ Closer to our own time, twentieth-century biology, under the spell of understanding DNA as a code-script, often conflated vitality and textuality; the "secret of life," genetic information, was imagined as the really real to the epiphenomenal world of the organ-

21. Tom Ray, "An Evolutionary Approach to Synthetic Biology: Zen and the Art of Creating Life," *Artificial Life* 1 (Fall 1993–Winter 1994): 183; my emphasis.

22. *Ibid.*, p. 184.

23. Oyama, *The Ontogeny of Information*, p. 27.

24. See Carol Delaney, "The Meaning of Paternity and the Virgin Birth Debate," *Man* 21 (Sept. 1986): 494–513. Such a reading aligns with Hayles's interpretation of an artificial life program created by Richard Dawkins as summoning imagery of a "male programmer mating with a female program to create progeny whose biomorphic diversity surpasses the father's imagination" (Hayles, "Narratives in Evolution and the Evolution of Narratives," in *Cooperation and Conflict in General Evolutionary Processes*, ed. John L. Casti and Anders Karlqvist [New York, 1994], p. 125).

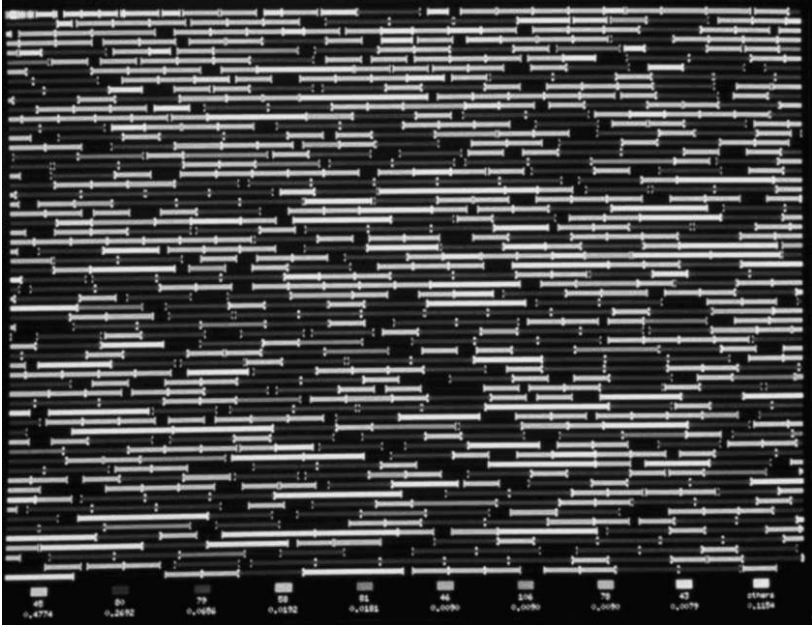


FIGURE 1. A screenshot of Tom Ray's Tierra System, visualizing space taken up by digital organisms within random-access memory (RAM) during one run of the program. Image made using the Artificial Life Monitor (ALmond) program developed by Marc Cygnus.

ism. Ray's Tierra simply takes a metaphor first offered by Schrödinger to its logical conclusion.

Such informatic visions appeared again and again in my fieldwork. Larry Yaeger, who programmed a system called PolyWorld, said to me, "I believe that there might actually be an information-based measure of the quantitative degree of life." Ken Karakotsios, programmer of SimLife, a popular Artificial Life game, said, "I started out looking at ALife as a computer architect and programmer. I've been trained to look at things as processes, where the same process can be run in different ways on different hardware architectures." Such visions fall in line with Langton's field-founding claim that, "the dynamic processes that constitute life—in whatever material bases they might occur—must share certain universal features—features that will allow us to recognize life by its dynamic form alone, *without reference to its matter*."²⁵ Such positions offer an extreme Platonism.

And they underwrite a structure of feeling among Artificial Life researchers, a sense that the informatic dynamics of "life" are immortal. For many practi-

25. Langton, "Artificial Life," in *Artificial Life*, p. 2; my emphasis.

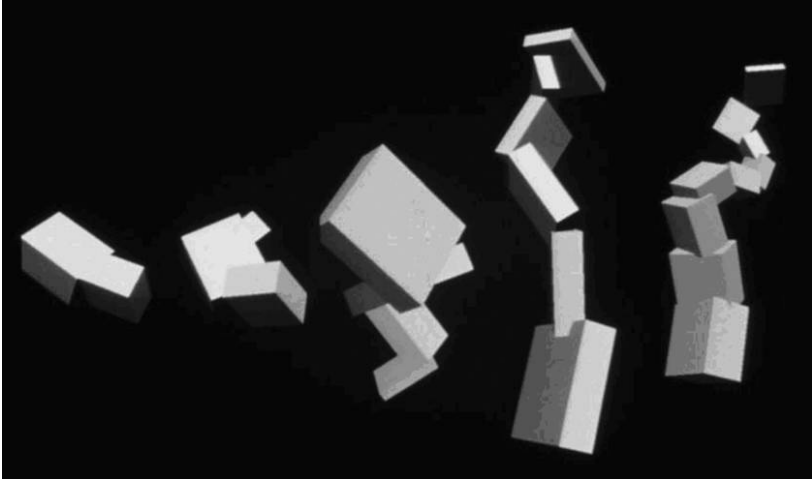


FIGURE 2. An evolutionary sequence of Sims's virtual creatures, selected for swimming. Courtesy of Karl Sims.

tioners, such a view offers a kind of cybernetically inflected spirituality—one akin to that celebrated by figures such as Ray Kurzweil and Hans Moravec, who believe that it may be possible to upload human consciousness into long-lived robots.²⁶ Here, life forms might be engineered to fit within a form of life that imagines itself as sculpted by and as sculpting an evolutionary narrative that prizes the continuation of life whatever its matter.

Performance

The other side of form for Artificial Life has been performance. That aspect presented itself strikingly at an Artificial Life conference I attended at MIT in 1994. At this gathering, Karl Sims gave a talk in which he showed a video of simulated creatures with boxes for arms, legs, torsos, and heads. These creatures were not animations but “evolved” pieces of software in a simulated universe, which space was visualized on computer screens as a three-dimensional world, complete with implied vanishing points. Using a technique called genetic programming, Sims treats the software running his programs as genetic code and assays the phenotypic performance of the code by running the programs. The role of natural selection is played by a fitness function aimed at testing for how the programs function appropriately to a given test (fig. 2). At MIT, Sims’s

26. See Geraci, *Apocalyptic AI*.

graphics allowed his audience to watch these creatures attempt various tasks in artificial worlds.

Sims's brilliance in explicating his work was to show video of his virtual organisms' performances, calibrated so they would run in what looked like real time. As they passed or flunked their Darwinian fitness tests, Sims's boxy critters elicited laughter. I joined Artificial Life scientists in their pleasure at these images and experienced the activity of the simulated creatures as cute, especially when they could be interpreted as valiantly failing at their tasks. What made the images funny was a sense that Sims was not fully in control; he had programmed a three-dimensional artificial world—and a visual representation of it—that simulated Newtonian physics, gravity, and fluid dynamics, and he had introduced creatures that could interact with this world. Because simulated physics and creatures were programmed together, behaviors looked realistic, even purposeful. By playing with the boundary between simulation and animation and by explaining the genetic program back end of the model, Sims bolstered his viewership's faith in the lifelike character of the simulations. The persuasive force of Sims's presentation is visual; watching a stream of computer code text would not have produced the same life-effect.²⁷ Life becomes a formal effect.

The lesson viewers took from this was that the field of biology does *not yet know* about all the forms across which life might exist—or be created. “Life” becomes abstractable, metaphysical, something that can be ported across substrates. What was life for Artificial Life? Pure form. And the ends of life are in its endless forms.²⁸ Form reaches out to embrace extreme, limit possibilities.

27. See Karl Sims, “Evolving 3D Morphology and Behavior by Competition,” *Artificial Life IV Proceedings*, ed. R. Brooks and P. Maes (Cambridge, Mass., 1994), pp. 28–39. Hayles, “Simulating Narratives: What Virtual Creatures Can Teach Us,” *Critical Inquiry* 26 (Autumn 1999): 1–26, provides a discussion of how technically and narratively to parse the functioning of Sims's program. While I agree with Hayles that an “adequate account of the simulation . . . requires expanding the boundaries of the system beyond the programs and computer to include the virtual world, the creator, and the viewer,” I disagree that this presses us to take on board a model of ourselves as part of a “distributed cognitive system” (p. 6). I find this move to reify cognition on the very calculative model Sims uses to motivate his claim for the ontological status of his world. Far from attending to “what virtual creatures can teach us,” this move surrenders to their rhetoric. Kelty and Landecker's “A Theory of Animation,” which argues that Artificial Life models not only posit but instantiate theories of life, is more agnostic about the ultimate nature of life or cognition. I find compelling, too, Doyle's argument that “what makes possible the substitution of the signs of life for life is the reproducibility of ‘lifelike behavior,’ a reproducibility that ultimately points to the fact that ALife organisms are themselves reproductions, simulations cut off from any ‘essence’ of life” (Doyle, *On beyond Living*, p. 122). More promising than chasing after an essence of “life itself” may be attending to how liveliness is a narrative effect; see Natasha Myers, *Molecular Embodiments: Modeling Proteins and Making Scientists in the Contemporary Biosciences* (forthcoming).

28. Helmreich, “‘Life Is a Verb’: Inflections of Artificial Life in Cultural Context,” *Artificial*

But, as Marilyn Strathern saw as early as 1992, the putatively oxymoronic “artificial life” hints at an undoing of the self-evidence of “life” as a natural kind.²⁹ As Jean Baudrillard would have had it, simulation reveals there was never an original.³⁰ When form is decoupled from life, we are left with free-floating form. In the bargain, “nature” becomes everywhere and nowhere, both completely given and thoroughly constructed; we are left in a zone that Strathern calls “after nature,” referring both to being postnature and enduringly in pursuit of it.³¹ Artificial Life can be read as a sign of the instability, the limits, of nature as an ontological category. Biology becomes ungrounded. The form of life prepared by belief in these life forms is one in which bioengineering practice can simultaneously lean on “life” as a category and know that it is constructed.³²

Marine Microbiology: Life Forms at Limits of Materiality and Relationality

At the same time, one could argue that “extreme nature” is the new “after nature.”³³ Such certainly seemed plausible to me when I switched gears after Artificial Life to examine the work of biologists studying microbes living at deep-sea hydrothermal vents, at extremes of temperature and pressure. Here were life forms—*extremophiles*, in scientific parlance—that pressed against the boundaries of what biologists believed living things capable of; these creatures made their living through chemosynthesis, the production of organic materials using energy from chemicals, such as hydrogen sulfide—a mode of life not discovered in the wild until the 1970s. If Artificial Life scripted life as detachable from particular substrates, the marine biology of extremophilic microbes construes life as possessed

Life 13, no. 2 (2007): 189–201, reviews the secondary literature on Artificial Life and also suggests that the present tense transitivity in *life-as-we-know-it* and the modal compound conditional mood of *life-as-it-could-be* could be joined by a whole series of possible other conjugations of “life as a verb”—from the future imperfect tense of *life-as-it-will-be-unfolding* to the preterite present of *life-as-it-may-be* to the present imperfect of *life-as-it-is-becoming*.

29. See Strathern, *Reproducing the Future*.

30. See Jean Baudrillard, *Simulations*, trans. Paul Foss, Paul Patton, and Philip Beitchman (New York, 1983).

31. See Strathern, *After Nature: English Kinship in the Late Twentieth Century* (Cambridge, 1992).

32. See, for example, “Meanings of ‘Life,’” an editorial that champions “synthetic biology’s view of life as a molecular process” as an antidote to moral claims about the life status of embryos, but at the same time argues that “we might now be permitted to dismiss the idea that life is a precise scientific concept” (“Meanings of ‘Life,’” *Nature* [28 June 2007]: 1031–32).

33. See Bill Curtsinger, *Extreme Nature: Images from the World’s Edge* (Pittsburg, Calif., 2005), and Mark Carwardine, *Extreme Nature: The Weirdest Animals and Plants on the Planet* (New York, 2008).

of an as-yet-unmapped elasticity—though one still anchored in organic chemistry. This is not abstract form, then, as in *Artificial Life*, but form plastic to extreme conditions, to limits. This angle is appropriate to the form of life known as environmentalism, concerned about material, embodied limits and flexibility in the biosphere (and also, in the age of environmental calamity, tuned to hopes that genetically engineered microbes might eat up oil spills and other toxic disasters). Here, life is surprising in its possible embodiments—this speaks less to Schrödinger’s answer to what is life? than to Margulis and Sagan’s.

Fieldwork I conducted among marine microbiologists in the early 2000s—with the Woods Hole Oceanographic Institute in Massachusetts, the Monterey Bay Aquarium Research Institute in California, and the University of Hawaii as key sites—saw me following scientists into labs, to conferences, out to sea. Trying to get a fix on how these people made microbial life legible, I spoke with them about their difficulties pinning down that most elementary of biological forms: the species. The categorical stability of species has been troublesome for at least a century in microbiology but has become a central worry in recent debates about how to

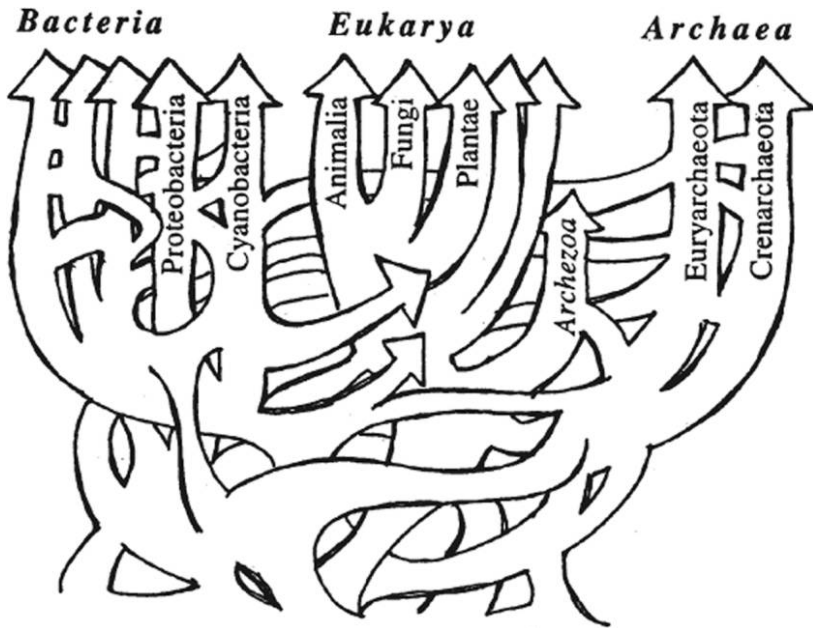


FIGURE 3. W. Ford Doolittle “A Reticulated Tree, or Net, Which Might More Appropriately Represent Life’s History” (from “Phylogenetic Classification and the Universal Tree,” *Science* (25 June 1999): 2127, fig. 3).

place marine microbes with respect to the origin of life on Earth. Some microbiologists believe life first emerged in the volcanic environs of hydrothermal vents. The origin story optimism that often suffuses the search for the last common ancestor among marine microbial organisms is flagged by the name under which deep-sea hyperthermophiles have traveled since 1977: the Archaea, or ancient ones. But without a microbial fossil record to draw on, microbiologists ground their case for archaeal antiquity in present-day microbial DNA, using this to reconstruct deep genealogies—seeking the root of what they call the universal tree of life, that representational branching structure that Charles Darwin advanced as a grid for organizing knowledge about the history of life on Earth.

As it turns out, lateral gene transfer in microbes—the travel of genes not just down generations, but rather across, within, among contemporaries—places treelike representations at risk. Ford Doolittle has argued that the tree of life might better be imagined as a net: “if . . . different genes give different trees, and there is no fair way to suppress this disagreement, then a species (or phylum) can ‘belong’ to many genera (or kingdoms) at the same time: *There really can be no universal phylogenetic tree of organisms based on such a reduction to genes.*”³⁴ The genealogy-jumbling work of gene transfer is thick in marine environments since, “given the very high concentrations of bacteria and viruses in seawater and the tremendous volume of water in the ocean, it follows that gene transfer between organisms takes place about 20 million billion times *per second* in the oceans.”³⁵ Doolittle offered a brambled tree model to represent what was becoming of the lines through which one might map the history of “life” (fig. 3).

Gene transfer interrupts what Darwin called the “natural classification” that would follow from following lines of descent.³⁶ In a microbiological restaging of those personalized, family genetic history tests that suggest that people’s “racial” and “ethnic” ancestries are more polyglot than they may have imagined, *species*, like the “pure” racial type, falls apart, denatures. In part, this is because sex—the generative center of classical biopolitics, joining together individuals and populations—is supplanted by transfer, which undoes the genealogical stability of the categories it brings into juxtaposition. It makes clear that there is no natural classification—that biology is bound up with human social purposes. Life forms are always described with respect to some form of life.

34. Doolittle, “Phylogenetic Classification and the Universal Tree,” p. 2127; my emphasis.

35. Frederic Bushman, *Lateral DNA Transfer: Mechanisms and Consequences* (Cold Spring Harbor, N.Y., 2002), p. 2.

36. Charles Darwin, *Natural Selection: Being the Second Part of His Big Species Book Written from 1856 to 1858*, ed. R. C. Stauffer (Cambridge, 1987), p. 249.

There are attempts to salvage something like species with the concept of the phylotype, a genetic but not genealogical classification. In this formulation, microbes might belong to the same phylotype if they show more than 70 percent genetic similarity. Doolittle and his colleagues have proposed a “synthesis of life” that makes use of both tree and net linkages to represent phylogenesis, defined, they record, by the *Oxford English Dictionary* as “the evolutionary development of a species or other group of organisms through a succession of forms,” which, they write, “in no way requires that species or other groups be produced solely through divergence, nor that diagrammatic representation of the evolutionary development of species must be a bifurcating tree.”³⁷

What is preserved in their new map is the figure of the gene, continuing to serve as a connecting thread, representing the flow of “life.” There is a tension between the real and represented in such mappings. Insofar as lateral gene transfer has fractured the arborescent model of microbial relatedness, it has done so via a detour into bioinformatic representation, a zone where genes are manipulated in a computational formalism. Ontological claims become anchored by the particularities of that representation—and unwindable through that same informatic infrastructure.³⁸ If Artificial Life took computer codes as genetic codes, full stop, bioinformatics is encountering their morphing similarity and difference, their unstable interoperability.³⁹ The Platonism of Artificial Life can no longer be sustained by today’s “computation in the wild.”⁴⁰

Categories—genetic, metabolic—proliferate. Some marine microbiologists I spoke with reveled in the complexity, making clear what this rearrangement of life forms might mean for forms of life. Some saw it underwriting a bioengineering form of life: “Natural genetic engineering,” one biotech booster told me, “is very common.”⁴¹ People with this view have argued for barcoding microbes—identifying organisms by their genetic profile while being completely agnostic about their evolutionary re-

37. Eric Baptiste et al., “Phylogenetic Reconstruction and Lateral Gene Transfer,” *Trends in Microbiology* 12 (Sept. 2004): 409. The authors argue that “a framework for natural classification should be based on a true understanding of historical processes,” though they also caution that “there might never be a perfectly natural classification” (ibid.).

38. See Hallam Stevens, *Life out of Sequence: An Ethnographic Account of Bioinformatics, from the ARPAnet to Postgenomics* (forthcoming).

39. See Adrian Mackenzie, “Bringing Sequences to Life: How Bioinformatics Corporealizes Sequence Data,” *New Genetics and Society* 22, no. 3 (2003): 315–32.

40. Brian Cantwell Smith, *On the Origin of Objects* (Cambridge, Mass., 1996), p. 28.

41. This corroborates Haraway’s sense that, in the genomic age, “nature [has become] a genetic engineer that continually exchanges, modifies, and invents new genes across various barriers” (Haraway, *Modest_WitnessSecond_Millennium.FemaleMan©_Meets_OncoMouse*™, p. 225).

lationship. Still others thought microbial webworks endorsed a thrillingly relational vision of the planet: "I like the idea of that picture of the tree that's all knotted and tangled," a postdoc in Monterey told me. "It fits with my view of the world, of everything being connected, as parts in a body, of a Gaian synthesis." Fernando de la Cruz and Julian Davies write, "it is clear that genes have flowed through the biosphere, as in a global organism."⁴² Thinking of the planet as a global organism has led some to speak of the "ocean genome," most prominently Craig Venter, who in 2004 embarked on a voyage in his private yacht to "sequence the Sargasso Sea." As he put it in explaining the Ocean Microbial Genome Survey he undertook from 2004–7, "by sequencing multiple sites we might be able to compile an actual sequence database of the ocean's genome."⁴³

What does all this mean for the form that life takes? It is multiple; even when reduced to genes, it flows all over the place. Marine microbiologists are clear that classifications are matters of framing. The form in "life forms" changes with scale and context. These scientists understand microbes with respect simultaneously to their genes, metabolisms, and interaction with one another in communities, ecologies, and global biogeochemical processes like the carbon cycle. Many of their theoretical and classificatory conundrums are about how to link, as they phrase it, genomes to biomes. The question, how to think about the forms life might take depends on which properties are relevant to the unit of description in question and on how sociopolitical frames—biotechnological, environmentalist—condition these choices, even as they are themselves summoned forth by biological knowledge in a complicated cycle in which life forms and forms of life recursively inform one another.

A dramatic effect on the category of "life" is that it oscillates between being located at the level of the gene and emergent at the level of the globe. Penny Chisholm said about *Prochlorococcus*, the world's most abundant photosynthetic marine bacterium: "I consider this the minimal life form—having the smallest number of genes that can make life from light and only inorganic compounds. It is the essence of life." But after explaining *Prochlorococcus*'s place in the modulation of Earth's biosphere, she concluded by offering that *Prochlorococcus* should guide biologists to "think of life as something with properties similar at all scales, a system of self-stabilizing networks. Life is a hierarchy of living systems."⁴⁴ Here, the metabolic, en-

42. Fernando de la Cruz and Julian Davies, "Horizontal Gene Transfer and the Origin of Species: Lessons from Bacteria," *Trends in Microbiology* 8 (Mar. 2000): 128.

43. Craig Venter, "Our World," 17 Mar. 2007, transcript at www.voanews.com/english/archive/2007-03/2007-03-16-voa3.cfm?CFID=84736433&CFTOKEN=35525614

44. Penny Chisholm, "How to Dominate the Oceans with 2000 Genes," paper delivered at the Arthur M. Sackler Colloquia of the National Academy of Sciences, 12–13 Dec. 2005.

ergetic aspect of vitality provides the lattice through which one can link genes to globe.

What are life forms here—in this realm of extreme metabolisms, jumbled genealogies, shifting scales? They are the result of how phenomena are contextualized, whether with respect to normal or exotic ecologies, with reference to genealogy, or through recalibrating relations of parts and wholes. The form in a life form is a sign of one's methodological and theoretical approach; in many ways it is an abstraction—even as microbiologists would also claim, contra Artificial Life, that forms cannot be *abstracted* from living things. While for some time Artificial Life participants like Francisco Varela living things could be thought of as autopoietic, as calling forth the conditions of their own existence through “interactions and transformations [that] continuously regenerate and realize the network of processes (relations) that produced them; and . . . constitute . . . [them] as . . . concrete unit[ies] in the space in which they exist,” then marine microbiologists who want to keep genomic, ecological, and Gaian processes simultaneously in view might be considered as hewing to a view of life forms as allopoietic, where relation (including interpretative relation), not unity, is the parameter within which form materializes.⁴⁵

What kind of limit have I detected here? It is something like extreme materialist relativism; while the word *extremophile* (“lover of extremes”)—coined in 1974 as a scientific-sounding hybrid of Latin *extremus* and Greek *philos*—has usually been taken to refer to microbial life forms, biologists point out that the term can apply to metazoans as well and, more, that “extremophily” is a relative term.⁴⁶ Humans might be imagined as aerophiles, air lovers—an extreme from the vantage point of anaerobes. The “extreme” functions as a relativist rather than totalizing operator. What this accomplishes is attention to environment; the ends of this kind of biology are about ecological context—and about displacing humans as the only ends of evolution. Such a view means to awaken humans to their superfluity to earthly life writ large and therefore to their responsibility for the effects of their anthropocentrism. This scalar, contextual “life,” always tumbling over its proper representation, is kin with contemporary ecopolitics, anxious about how properly to stage the scale and level of biological intervention in a time of environmental crisis, in a time when both

45. Francisco J. Varela, *Principles of Biological Autonomy* (New York, 1979), p. 13. One might also call it, following a recent coinage of Scott F. Gilbert, *sympioiosis*. See Gilbert et al., “Symbiosis as a Source of Selectable Epigenetic Variation: Taking the Heat for the Big Guy,” *Philosophical Transactions of the Royal Society B*, 365 (2010): 671–78.

46. R. D. Macelroy, “Some Comments on the Evolution of Extremophiles,” *Biosystems* 6 (1974): 74–75.

nature and society seem to be pushing against their own and each other's limits.

Astrobiology: Life Forms at Limits of Definition

In 1998, NASA founded the Astrobiology Institute, distributed across a number of universities and research facilities. Scientists working in astrobiology experiment with extremophiles as analogs to extraterrestrial life. They also look to other planets for what they call "the signature of life" or often simply a "biosignature," defined as "any measurable property of a planetary object, its atmosphere, its oceans, its geologic formations, or its samples that suggests that life was or is present. A short definition is a 'fingerprint of life.'"⁴⁷ According to common wisdom in the field, there are direct and remote signatures of extraterrestrial life. Direct signatures include measurements that show evidence (in extraterrestrial rock samples, for example) of the production of organic molecules. Remote signatures include such items as the spectral signature of other worlds' atmospheres, which can point toward such bioproducts as ozone or methane. Astrobiologists often zero in on the spectral trace of water as an indication of the possibility of vitality. A founding challenge, according to David Des Marais, is that "our definitions are based upon life on Earth" and that, "accordingly, we must distinguish between attributes of life that are truly universal versus those that solely reflect the particular history of our own biosphere."⁴⁸ This is no simple task, since knowing what is universal is precisely what is to be discovered.

If the Search for Extraterrestrial Intelligence (SETI) sought signals in an ocean of noise, looking for the arbitrary and organized surprise—what scientists call information—astrobiology searches in a less Saussurian mode, scouting for what Charles Sanders Peirce called indices—indirect representations or traces of its object, life. Indeed, insofar as astrobiology has replaced SETI, this is a sign of the ascendancy of biology as a source of funding for space science.

The question of what would count as a proper trace remains vital. Several scientists referred me to the most famous picture in their field, an electron microscope image of the inside of a Martian meteorite discovered in Antarctica in 1984 (fig. 4). Mars meteorite ALH84001, which had been blasted off Mars 16 million years previous by the impact of another meteorite and had arrived on Earth 13 thousand years ago, harbors elliptical

47. David S. McKay et al., "Recognizing and Interpreting Biosignatures, Abstract # 12873 (Oral Presentation)—The Classification of Biosignatures," *Astrobiology* 2, no. 4 (2002): 625–26.

48. David J. Des Marais et al., "Remote Sensing of Planetary Properties and Biosignatures on Extrasolar Terrestrial Planets," *Astrobiology* 2, no. 2 (2002): 154.

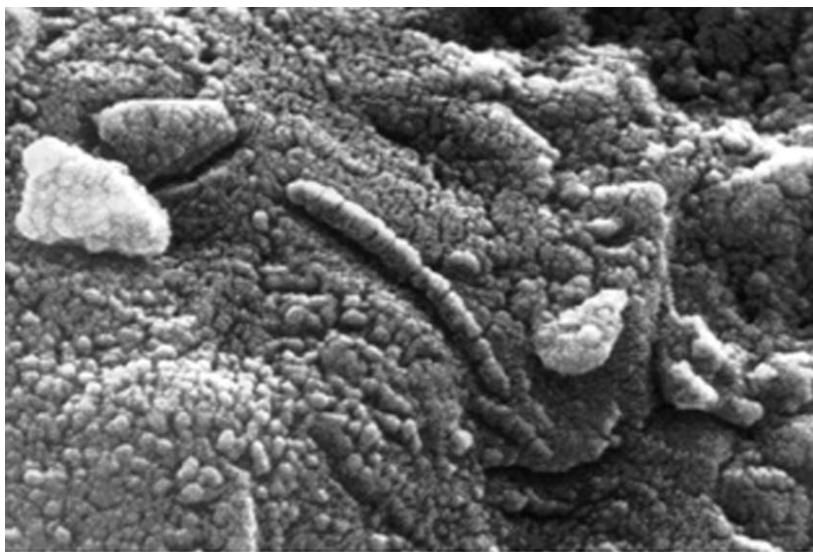


FIGURE 4. Ovoid forms inside Martian meteorite ALH84001, as depicted through scanning electron microscopy. The elongated shape in the center is some several hundred nanometers in length. See McKay et al., "Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001," *Science* (1996): 924–30. Photo: NASA.

shapes some believe to be outlines of ancient microbial life. David McKay and colleagues wrote, "Ovoid features . . . are similar in size and shape to nannobacteria in travertine and limestone. The elongate forms . . . resemble some forms of fossilized filamentous bacteria in the terrestrial fossil record." They concluded that they had found "evidence for primitive life on early Mars" with an age of about 1.3 to 3.6 billion years.⁴⁹ Their evidence, arrived at through the amplification of electron microscopy, offered a similitude that did not convince astrobiologists who balked at pattern-matching recipes for seeing traces of life in ALH84001.⁵⁰ Still, advocates' arguments went beyond visual pattern matching; there were also traces of organic carbon compounds (though either biotic or abiotic processes could have produced these) as well as magnetite and sulfides similar to those made by earthly bacteria. Many opponents pointed out that traces on ALH84001 indicated formations two orders of magnitude smaller than any microbe, too cramped to enclose all of the apparatus cells need to func-

49. McKay et al., "Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001," pp. 929–30.

50. See A. H. Treiman, "Submicron Magnetite Grains and Carbon Compounds in Martian Meteorite ALH84001: Inorganic, Abiotic Formation by Shock and Thermal Metamorphism," *Astrobiology* 3, no. 2 (2003): 369–92.

tion. Supporters of life signs in ALH84001 countered that these were not microbes but nanobes—a reframing that recognizes a limit but then leaps over it by conjuring a new category.⁵¹

A constant repositioning of what life could be—and the form it might take—is a feature in astrobiological discourse. In a 2007 report jointly issued by the United States National Research Council's Committee on the Limits of Organic Life in Planetary Systems and Committee on the Origins and Evolution of Life, biologists interested in the possibility of life on other planets speculate that living systems might employ ammonia, sulfuric acid, and methane as a solvent in the way life on Earth uses water.⁵² Such claims open up the possibility of looking in as-yet-unexamined locales for life, such as the methane lakes of Saturn's moon, Titan. Such a framing poses life as at once materially anchored and capable of taking a variety of forms not yet known. Indeed, the opening inscription of the report reads, "Dedicated to Non-Human-Like Life Forms, Wherever They Are."⁵³ Leaving aside the fact that "non-human-like" might better read "unknown" or "extraterrestrial," this statement is an expression of faith in form and, in its way, life.

What are life forms for astrobiology, then? Things that leave *traces* of their form. And astrobiologists are adamant that they do not yet know what all these forms could be, that they will always be operating at the limits of their knowledge. They hold that there are many logics from which to reason about extraterrestrial life—from Earth analogs, from organic chemistry, from spectroscopy. As Baruch Blumberg suggests, "life has the characteristic, using philosophical terminology, of 'being' and 'becoming.' It exists in a particular form now, but has the potential, because of the diversity in its offspring, of becoming something related, but also different."⁵⁴ Within this awareness (phrased though it is in terms of inheritance) is a sense that astrobiology depends on what Peirce called "abduction," the argument from the future.⁵⁵ "Life" is revealed not just as the endpoint of

51. For early speculation on nanobes in ALH84001, see Philippa J. R. Uwins, Richard J. Webb, and Anthony P. Taylor, "Novel Nano-organisms from Australian Sandstones," *American Mineralogist* 83 (1998): 1541–50.

52. Committee on the Limits of Organic Life in Planetary Systems et al., *The Limits of Organic Life in Planetary Systems* (Washington, DC, 2007).

53. *Ibid.*, p. viii.

54. Baruch S. Blumberg, "The NASA Astrobiology Institute: Early History and Organization," *Astrobiology* 2, no. 3 (2003): 470.

55. Or, perhaps, *revelation*. The Vatican has taken an interest in astrobiology, with a Study Week on Astrobiology convened by the Pontifical Academy of Science in November 2009. The abductive charter of astrobiology also leaves it open to the possibility of hoaxes. For an intriguing argument on this score, see Kember, "Media, Mars, and Metamorphosis," *Culture Machine* 11 (2010): 31–40.

processes of deduction (as in early vitalist accounts that knew life when they saw it) or induction (as with Darwin, who reasoned up to what life's processes might be from empirical data), but also of abduction, which rests on a faith in the intelligibility of future cases.⁵⁶ Astrobiologists live firmly in the domain of Strathern's "after nature." But they also live in the time of "extreme nature," nature imagined as host to entities that push its own limits. This extreme nature is a secularized supernatural because its orbit extends beyond and embraces our planet, but also because the "natural," encountered elsewhere, intimates its own incompleteness as a source of explanation.

Limit or extreme natures necessarily fold back to ask questions about "normal" nature. Astrobiologists' sense that life may have different conformations elsewhere in the universe is leading some to ask whether life may have originated more than once on Earth. Astrobiologists now ask whether such life might have left traces of its multiple origins. Known living things are made of left-handed amino acids and right-handed sugars, but this handedness is, it is largely agreed, contingent; molecules could have twisted the other way, with right-handed amino acids and left-handed sugars making up the molecular mechanics of earthly life. Paul Davies has lately asked whether there may exist on Earth "shadow terrestrial biospheres of alternative life forms."⁵⁷

The forms of life at stake in this reimagining of the spaces within which life forms might manifest are multiple. At the institutional level, space science leverages uncertainty into institutional support. In a political economic register, as Melinda Cooper has suggested, the stretching of the limits of life may be keyed to an economic moment, one in which the notion of the untapped biological resource has constantly to be reinvented.⁵⁸ That framing suggests that the extreme or limit may be, like the mania that Emily Martin finds valorized in popular culture and psychology, a sign not of the ending of biology but of its bending toward a political economic purpose.⁵⁹ But the form of life in the making is also one that

56. See Helmreich and Roosth, "Life Forms."

57. Paul Davies, "Searching for Multiple Origins of Life," in program for "Study Week on Astrobiology," Vatican City, 6–10 Nov. 2009, Program, p. 10.

58. See Cooper, *Life as Surplus*.

59. See Emily Martin, *Bipolar Expeditions: Mania and Depression in American Culture* (Princeton, N.J., 2007). Such an account would nest "biological theory" as an effect of capital, much as Terry Eagleton saw theory as a cultural production of capital, though one that, as culture, inherited a demand to be reflexive about its conditions of emergence. See Terry Eagleton, *After Theory* (London, 2003). See also Steven Knapp and Walter Benn Michaels, "Against Theory," *Critical Inquiry* 8 (Summer 1982): 723–42 for a caution against claims in this register.

situates earthly life into a cosmic context that is increasingly ecological in its depiction.⁶⁰ That fact makes clear, again, that life forms and forms of life not only inform one another (especially after biopolitics) but that the two may be impossible to disentangle, especially since they treat a life that is increasingly known to be both real and constructed, social and natural.

What Was Life?

W. J. T. Mitchell writes in a recent work that “there is . . . a new kind of vitalism and animism in the air, a new interest in Nature with a capital N. . . . The philosophy of life has returned with a vengeance in the age of biogenetic engineering and bio-terrorism.”⁶¹ But, alongside this view, Eduardo Kac and Avital Ronell, in their book about art in the age of genetic engineering, *Life Extreme*, suggest that, in this same moment, “the stability of life or of the living is thrown off course.”⁶² I agree. One of the concomitants of such a throwing-off-course is a fascination with extremes and limits.

The three limit biologies I have examined here indicate instabilities in the nature supposed to ground life. And they all do so through a wiggling of what is meant by the form that life takes, a loosening that suggests epistemic shifts in the biological sciences generally; in the age of synthetic biology, biologists know full well that their knowledge is, in addition to an attempt to describe the organic world, a thick epistemological construction.⁶³ This puts biology as a universalizing science at risk, one reason these limit biologies come with the promise to reboot the life sciences. That promise may be read out of the argument of images the reader will have detected accompanying this essay. All the figures I reproduce—which I would argue are representative of their various fields—refer to elementary forms of life, a limit of beginnings.

The three biologies I have presented make explicit the instability of “life” in such other domains as reproductive technology, biodiversity, and biosecurity. The very appearance of the word *life* in quotation marks—in this essay, but also in many of the sources I cite—indicates a social dissensus about its meaning.⁶⁴ And a fascination with limits operates

60. See Valerie A. Olson, “The Ecobiopolitics of Space Biomedicine,” *Medical Anthropology: Cross-Cultural Studies in Health and Illness* 29, no. 2 (2010): 170–93.

61. W. J. T. Mitchell, “The Rights of Things,” foreword to Cary Wolfe, *Animal Rites: American Culture, the Discourse of Species, and Posthumanist Theory* (Chicago, 2003), p. xiii.

62. Kac and Avital Ronell, *Life Extreme: An Illustrated Guide to New Life* (Paris, 2007), p. 13.

63. See Roosth, “Crafting Life: A Sensory Ethnography of Fabricated Biologies” (PhD diss., MIT, 2010).

64. See Raymond Williams, *Keywords: A Vocabulary of Culture and Society* (New York, 1976). And see Fischer, *Emergent Forms of Life and the Anthropological Voice* for a claim about a contemporary crisis of meaning in the life sciences.

not only among biologists I have studied but also in my own decision to study limit biologies.

What is a limit? It is the point at which an identity uncouples from itself, shades or snaps into something else. In thinking through limits, I find useful the work of Alberto Corsín Jiménez and Rane Willerslev, who have examined how the Yukaghirs, a hunter-gathering group in Siberia, think of their two primary hunting economies—of elk and sable, organized, respectively, around ad hoc egalitarian collections of people or around close, hierarchical kin groups—as “shadows,” or hidden sides, of one another.⁶⁵ The two modes of practice haunt one another, and it is possible for the one to transform into the other, rendering it impossible to decide which grounds the “real” economy. Jiménez and Willerslev, drawing on Eugenio Trias, write that “at the moment of their conceptual *limitation* (the moment when they stand at the end [*fin*] of their worlds, their *defining* moment), concepts capture their own shadow and become something other than what they are” (“AC,” p. 538).⁶⁶ Jiménez and Willerslev argue for “a view of concepts that stresses not only their capacity for providing stable meanings but also their ability to out-place themselves too, to unsettle their own reificatory tendencies” (“AC,” p. 528). Perhaps that has been part of my own attraction to the concept of “life,” for, as Jiménez and Willerslev suggest, “concepts create their own spaces for expression and . . . draw their own limits behind and around their shadows.” The limit, they write, “is also the place where the concept out-grows its shadow, and becomes something else” (“AC,” pp. 537–38). In the examples I have offered here, form becomes the shadow of life, only to outgrow it—at the same time as biologists continue to try to recapture it; no surprise that astrobiologists now explicitly discuss shadow life.⁶⁷

What is the shadow of life? The first-draft answer would of course be

65. See Alberto Corsín Jiménez and Rane Willerslev, “‘An Anthropological Concept of the Concept’: Reversibility among the Siberian Yukaghirs,” *Journal of the Royal Anthropological Institute* 13 (2007): 527–44; hereafter abbreviated “AC.” See also Strathern, “Sharing, Stealing, and Borrowing Simultaneously,” in *Ownership and Appropriation*, ed. Veronica Strang and Mark Busse (Oxford, 2011), pp. 23–42.

66. Jiménez and Willerslev’s reflections aim at asking anthropologists to be mindful of their own definitional work: “we might do more justice to ethnography if we attend to its own moments of re-description and look to how indigenous concepts find residency in their own accounts: from sexual seduction to love, to guile, and death, and so on. What is needed, then, is to open up within every conceptual description an ulterior space for future descriptions” (“AC,” p. 537).

67. And no surprise that, faced with the implosion of their enterprise, Artificial Life scientists have lately claimed that they seek to embed their science within the larger study of living technology. See Mark A. Bedau et al., “Living Technology: Exploiting Life’s Principles in Technology,” *Artificial Life* 16, no. 1 (2010): 89–97.

death—and a good case could be made that today's biopolitics are ever more entangled with necropolitics. But this is not quite right, since the better question is: what can we see in the shadow of life's limit? Answer: the absence of a theory for biology; reaching the limit of life reveals what was there all along, that there is no once and for all theoretical grounding for life. And, so, the Berkeley conference that asked, what's left of life? might fruitfully be put alongside the 2000 book to which its name alludes, *What's Left of Theory?*⁶⁸ which asks how Left political concerns with social justice might find moorings in scholarly work after poststructuralism. Theory had accomplished epistemological work that disturbed the making of dominant social norms and forms, but it had also produced what some people worried was an agnosticism about politics and ethics. At "What's Left of Life?" conferees meditated on ongoing wars, genocides, epidemics, genomics, life extension technologies, assisted reproduction, pharmaceuticals and potential stem-cell therapeutics to ask how life is defined and constituted, by whom, and in what specific disciplinary contexts; what kinds of tensions and contestations take place under the sign of life—the meaning of "life" seems, similarly to theory, to have raised anxieties about how properly to think and act in a moment of epistemological dizziness.

In *Life.after.Theory*, John Schad writes that "theory has made us wary of the idea of Life, or indeed any other organicist master-word."⁶⁹ But "life" and theory may also be read as doubles of one another. Schad ventures such a connection for theory as it came to be known in the late twentieth century:

To suggest that theory is, in its turn, a response to the Second World War is, in fact, to say that theory is 'life' in the strict etymological sense of the word—for 'life' comes from the prehistoric German *lib* meaning 'remain' or 'be left' and, as one dictionary puts it, 'the semantic connection between "remaining" and *life* . . . is thought to lie in the notion of being "left alive after a battle"'. If life is necessarily, *after-life*; if all living is a form of 'living-on,' in particular living-on after war, then theory is very much a form of life.⁷⁰

While the limit biologies I have examined here emerged well after World War II, they are of course contemporary with crises of many kinds. And, if anything, in current academic discussions, life and theory now

68. See *What's Left of Theory?: New Work on the Politics of Literary Theory*, ed. Judith Butler, John Guillory, and Kendall Thomas (New York, 2000).

69. John Schad, "Epilogue: Coming Back to 'Life,'" in *Life.after.Theory*, ed. Michael Payne and Schad (London, 2003), p. 172.

70. *Ibid.*, pp. 175–76.

double or shadow one another more densely than ever (with all the elongating, warping, and bending this implies). At the very moment when life is at stake in the biopolitics of disaster, human rights, and war, bio becomes ungrounded—with Giorgio Agamben's revival of *zoē*, bare life, a last-ditch patch, even a refetishizing of the biological.⁷¹ Theory, meanwhile—like life for biology, an attempt to represent and register a world of difference—finds itself the subject of worries about its adequacy in a postpostmodern world.⁷² Life and theory, wavering, gesture toward indeterminacy about where politics might now reside, about how life forms and forms of life form and deform in the shadow that has overtaken life after theory.

71. See Giorgio Agamben, *Homo Sacer: Sovereign Power and Bare Life*, trans. Daniel Heller-Roazen (Stanford, Calif., 1998). It may be worth revisiting Haraway's claim that "biopolitics is a flaccid premonition of cyborg politics," which unasks the question of how to ground life or theory (Haraway, "A Cyborg Manifesto: Science, Technology, and Socialist-Feminism in the Late Twentieth Century," *Simians, Cyborgs, and Women: The Reinvention of Nature* [New York, 1991], p. 150).

72. This does not mean that the quest for theory, in the life sciences or in the humanities, is over. While Peter Galison has argued that the sciences now look not for grand theory but for "specific theory," keyed to disciplines, subfields, and so on (Galison, "Specific Theory," *Critical Inquiry* 30 [Winter 2004]: 379–83), astrobiologically-minded cosmologists in 2010 leapt on beyond the universal into the *metaversal*. Alejandro Jenkins and Gilad Perez argued that "multiple other universes—each with its own laws of physics—may have emerged from the same primordial vacuum that gave rise to ours" and "may contain intricate structures and perhaps even some forms of life," suggesting that our universe might not be the only one uniquely suited to life (Jenkins and Perez, "Looking for Life in the Multiverse: Universes with Different Physical Laws Might Still Be Habitable" *Scientific American* 302 [Jan. 2010]: 42.). And while W. J. T. Mitchell has suggested that we might be moving into a moment of "medium theory"—theory calibrated to moderate claims, retreating from epochal pronouncements—Derek Attridge and Jane Elliott's *Theory after 'Theory'* continues to keep putting one foot after another to overcome limits; see W. J. T. Mitchell, "Medium Theory: Preface to the 2003 *Critical Inquiry* Symposium," *Critical Inquiry* 30 (Winter 2004): 324–35, and *Theory after 'Theory,'* ed. Attridge and Elliott (London, 2011). See also "What's the Difference? The Question of Theory," ed. Elizabeth Weed and Ellen Rooney, a special issue of *Differences* 21, no. 1 (2010), and "Theory Now," ed. Grant Farred and Michael Hardt, a special issue of the *South Atlantic Quarterly* 110 (Autumn 2011).