CHAPTER 1

WHAT WAS LIFE?

Answers from Three Limit Biologies

"What was life? No one knew."

—*Thomas Mann,* The Magic Mountain, *1924*

WHAT IS LIFE? A GATHERING consensus in anthropology, science studies, philosophy of biology, and even the biological sciences themselves suggests that the theoretical object of biology, "life," is today in transformation, if not dissolution. Proliferating technologies of assisted reproduction, along with genomic reshufflings of biomatter in such practices as cloning, have unwound the "facts of life."[1] Biotechnology, biodiversity, bioprospecting, biosecurity, biotransfer, and other things *bio-* draw novel lines of property and protection around organisms and their elements (e.g., genes, organs), which now circulate in new ways as gifts, as commodities, and as tokens of social belonging or exclusion.[2] From cultural theorists and historians of science we learn that "life itself," consolidated as the object of the discipline of biology around 1800, has morphed, as material components of living things—cells and genes—rearrange and disperse, and exist in distributed laboratory choreographies that have them frozen, amplified, and exchanged.[3] Writers in philosophy, rhetoric, and cultural studies of science, 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 unsteady any naturalistic or ultimate 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 language of anthropology, these changes unsettle the *nature* so often imagined to ground *culture*. Life moves out of the domain of the given into the contingent, appearing not as a thing-in-itself, but as something-in-the-making in discourse and in practice. "Life" becomes

a term increasingly placed within scare quotes—even in the pages of the most cited scientific journal in the world, *Nature*, which (as I report in the introductory chapter to this book) in 2007 published "Meanings of 'Life,'" an editorial calling for the abandonment of "life" as a scientific term of art. "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 discipline-dubbing book, *Biologie*, the German naturalist Gottfried Reinhold Treviranus asked, "What is life?" a question that, as it has traveled into the present, has admitted of various answers.[6] The physicist Erwin Schrödinger's 1944 *What Is Life?* 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.[7] Fifty-one years after Schrödinger, the microbiologist Lynn Margulis and the writer 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, protists, animals, fungi, and plants—emphasizing neither some underlying logic nor an overarching metaphysics but rather the situated particulars of microbial, fungal, plant, and animal embodiment; life was not something that could be compressed into the linear logic of a code but instead was a process ever overcoming itself in an assortment of embodied 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 many contemporary forms of hope and worry.

But if it is now possible to think of life as having a variety of plural 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 limit question, 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 rhetorician Richard Doyle, become possible?

> "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]

If, as Foucault argued, biopolitics brought "life and its mechanisms into the realm of explicit calculations"—that is, if it drew on life science knowledge to organize practices of governance (public health programs, reproductive policies, etc.)—what happens to such politics as life delaminates, escapes itself?[12]

Where is life off to?

What *was* life?

This essay offers possible answers to those questions, drawing on anthropological fieldwork I conducted among biologists in the late 1990s and in the first decade of the 2000s. In that ethnographic work, I pursued the question of what "life" is becoming for those professional biologists who worry very explicitly 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 might unify all possible cases. In the three scientific communities I studied, such limit accounts of life forms are tethered—sometimes explicitly, more often implicitly—to claims about the forms of cultural 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.

THREE LIMIT BIOLOGIES

In the 1990s, scientists working in the field of Artificial Life dedicated themselves to modeling evolutionary and 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 analyzed how scientists working 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 sought 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 ecological forms of life (e.g., the consumption of fossil fuels) might encounter or, perhaps, overcome biological limits. With work with microbes that engage in lateral gene transfer—mixing up genes "within" generations, that is, with their contemporaries—even taxonomy, the naming of life forms, became unstable, with implications for apprehending the possible natural and technical malleability 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 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 that such findings can be read back to situate Earthly life in a cosmic ecology.

I here read across these three ethnographic examples to suggest that biological studies in which "life" is conceptually stretched to a limit resonate with uncertainties about what kinds of sociocultural forms of life biology might now anchor. Limit biologies such as Artificial Life, extreme marine microbiology, and astrobiology can be read as symptomatic of the emergence elsewhere, in less ivory-towerish zones of practice, of growing instabilities in concepts of nature—organic, earthly, cosmic.[16] Such instabilities can be fruitfully mapped by attending to how scientists of extreme biologies test the limits of *form* in life forms.[17] If, as Treviranus wrote in *Biologie*, "the objects of our research will be the different forms and manifestations of life," those forms are being deformed by the object and form of biological inquiry.[18] While 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 the essay's close, I train attention on limits in order to understand some limits of "theory" today, as it is transforming within both professional biological discourse and critical inquiry.

ARTIFICIAL LIFE: LIFE FORMS AT THE 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 by 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.[19] My 1990s fieldwork among Artificial Life scientists was centered at New Mexico's Santa Fe Institute for 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."[20] Some found this claim so persuasive that they held that life forms could exist in the digital medium of cyberspace; they hoped that 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.

The founder, Chris Langton, characterized the ethos behind Artificial Life as animated by "the attempt to abstract the logical form of life in different material forms."[21] 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.

INFORMATION

Artificial Life founded its reputation on computational models of evolutionary dynamics. One of the most popular models during my fieldwork was the biologist 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 (see figure 1.1). For Ray, who was trained as a tropical ecologist and self-taught as a programmer, Tierra was not so much a *model* of evolution as it was "an *instantiation* of evolution by natural selection in the computational medium." "Digital life," Ray wrote, "exists in a logical, not material, informational universe."[22] Ray understood life to be a process of information replication and, like many of his Artificial Life colleagues, interpreted genetic code as analogous to computer code; in fact, the analogy was so tight that he considered it an

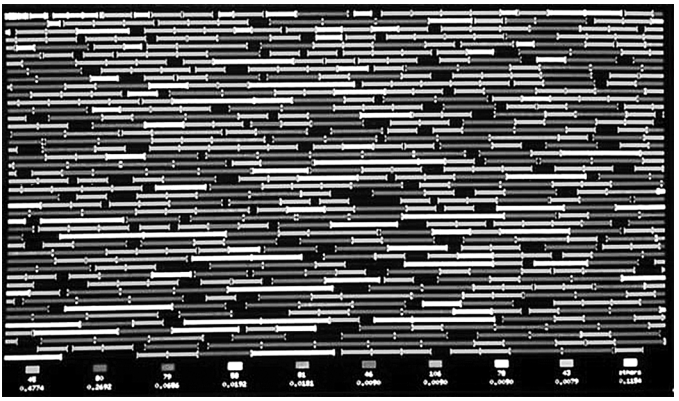

Figure 1.1. A screenshot of Tom Ray's Tierra, visualizing space taken up by "digital organisms" within random-access memory (RAM) during one run of the Tierra program. Images made using the Artificial Life Monitor (ALmond) program developed by Marc Cygnus. Image: Marc Cygnus. Used with permission.

identity. "The 'body' of a digital organism," he urged, "is the information pattern in memory that constitutes its machine language program."[23]

The idea that genes are informational 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 summarizes the position, "information . . . exists before the interactions in which it appears."[24] 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.[25] 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 organism. 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*."[26] Such positions offer an extreme Platonism.

And they underwrote a structure of feeling among Artificial Life researchers, a sense that the informational dynamics of "life" were immortal. For many practitioners, such a view offered a kind of cybernetically inflected spirituality—one akin to that still celebrated by figures such as Ray Kurzweil, who believes that it may be possible to upload human consciousness into long-lived robots.[27] 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.[28]

PERFORMANCE

The other side of form for Artificial Life was per*form*ance. That aspect presented itself strikingly at an Artificial Life conference I attended at MIT in 1994. At this gathering, the computer scientist Karl Sims gave a talk in which he showed a video of simulated creatures with boxes for arms, legs, torsos, and heads. These

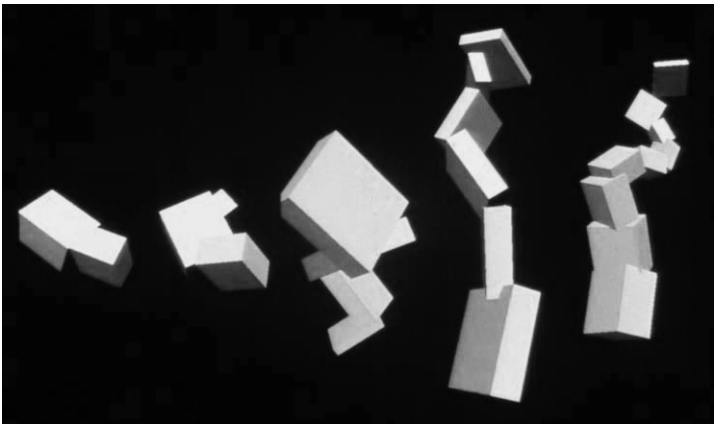

Figure 1.2. An evolutionary sequence of Sims's virtual creatures, selected for "swimming." Courtesy of Karl Sims.

creatures were not simple animations but actually "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 treated the software running his programs as "genetic code" and assayed the "phenotypic" performance of the code by running the programs. The role of "natural selection" was played by a "fitness function" aimed at testing for whether the programs would function appropriately to a given test (see figure 1.2). At MIT, Sims's graphics allowed his audience to watch these "creatures" attempt various tasks in artificial worlds.

Sims's brilliance in explicating his work was to show videos 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 the simulated physics and creatures were programmed together, their 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 was visual; watching a stream of computer code text would not have produced the same life vibe.[29] Life was here 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 would be in its endless forms.[30] Form reaches out to embrace extreme, limit possibilities.

But as the anthropologist 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.[31] As the philosopher Jean Baudrillard would have had it, simulation reveals there was never an original.[32] 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 post-nature and enduringly in pursuit of it.[33] 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.[34]

MARINE MICROBIOLOGY: LIFE FORMS AT THE LIMITS OF MATERIALITY AND RELATIONALITY

At the same time, one could argue that "extreme nature" is the new "after nature."[35] Such certainly seemed plausible 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 pushed against the boundaries of what biologists believed living things were capable of; these creatures made their living not through photosynthesis, but through *chemosynthesis*, the production of organic materials using energy from chemicals, such as hydrogen sulfide. If Artificial Life scripted life as detachable from particular substrates, the marine biology of extremophilic microbes construed life as possessed of an as-yet-unmapped elasticity—though always one grounded in organic chemistry. 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, which is 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 singular answer to the question, What is life? than to Margulis and Sagan's multiple choices.

Fieldwork 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—had me following scientists into labs, to conferences, and out to sea. Trying 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 stability of species has been troublesome for a while in microbiology but has become a central worry in debates about how to 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—and 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 for a while: the Archaea, or "ancient ones." But without a microbial fossil record to draw on, microbiologists have grounded their case 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 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 "down" generations but rather across, within, and among contemporaries, which then change their genetic identities within their lifetimes—places at risk treelike representations. The microbiologist Ford Doolittle argued in a 1999 paper in *Science* 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."[36] 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."[37] Doolittle offered a brambled tree model to represent what was becoming of the lines through which one might map the history of "life" (see figure 1.3).

Gene transfer interrupts what Darwin called the "natural classification" that would follow from tracking lines of descent. In a microbiological restaging of those personalized, family-genetic-history algorithms advertised for people curious about whether they have a haplotype that links them to, say, Genghis Khan, *species*, like the "pure" racial type, falls apart, denatures, and points in all sorts of possible directions.[38] In part, this is because "sex"—the obligatory passage point of what Foucault called *biopolitics*, joining together individuals and populations—is supplanted by "transfer"—an asexual, many-directioned connection, which undoes the stability of the very 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.

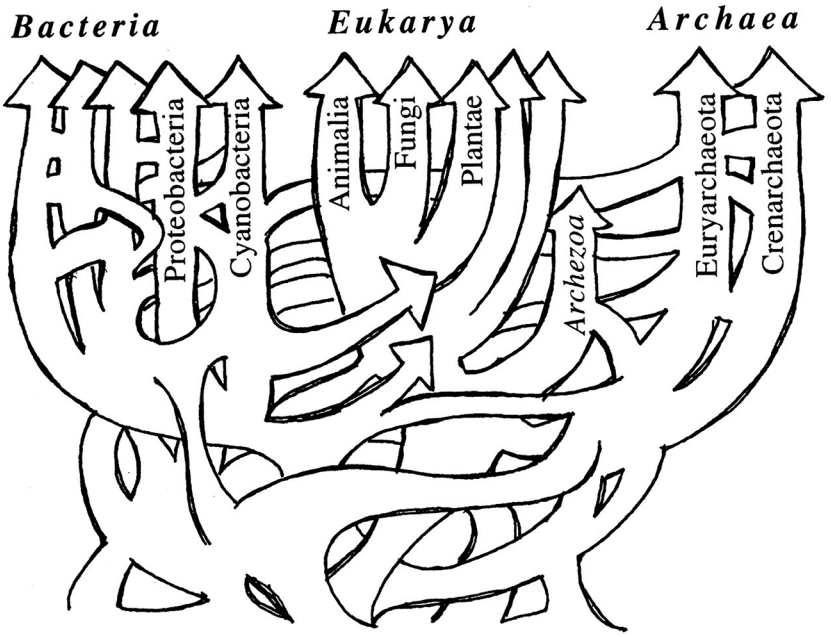

Figure 1.3. "A Reticulated Tree, or Net, Which Might More Appropriately Represent Life's History" Figure 3 from W. Ford Doolittle, "Phylogenetic Classification and the Universal Tree," *Science* 284 (1999): 2124–2128, at 2127. Reprinted with permission from AAAS.

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."[39]

What is preserved in their new map is the figure of the gene, which continues to serve as a connecting thread and represents 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 formatted by the particularities of that representation—and unwindable through that same informatic infrastructure.[40] If Artificial Life took computer codes as

genetic codes, full stop, bioinformatics is encountering their morphing similarity and difference, their unstable interoperability.[41] The Platonism of Artificial Life can no longer be sustained by today's computation-in-the-wild.[42]

Categories—genetic, metabolic—proliferate. Some marine microbiologists revel in the complexity, making clear what this rearrangement of life forms might mean for forms of life. Some see it underwriting a bioengineering form of life: "Natural genetic engineering," one biotech booster told me, "is very common."[43] People of this view have argued for "bar-coding" microbes—identifying organisms by their genetic profile while being completely agnostic about their evolutionary relationship.[44] Still others think of microbial webworks as endorsing a thrillingly relational vision of the planet: "I like the idea of that picture of the tree that's all knotted and tangled," the Monterey postdoc Steven Hallam told me in 2003. "It fits with my view of the world, of everything being connected, as parts in a body, of a Gaian synthesis." In *Trends in Microbiology*, Fernando de la Cruz and Julian Davies state, "It is clear that genes have flowed through the biosphere, as in a global organism."[45] 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, which he undertook from 2004 to 2007, "by sequencing multiple sites we might be able to compile an actual sequence database of the ocean's genome."[46]

What does all this mean for the form that "life" takes? That 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, in ecologies, and in 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 of 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 cycle in which life forms and forms of life recursively (though never perfectly) inform one another.

A dramatic effect on the category of "life" is that it oscillates between being located at the level of (at least) the gene and emergent at the level of the globe. The MIT microbiologist Penny Chisholm, in a 2004 talk entitled "How to Dominate the Oceans with 2000 Genes," had this to say 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."[47] 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." Here, the metabolic, energetic 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, and 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 "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. If for occasional Artificial Life participants, such as the late phenomenologist-biologist 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 a 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.[48]

What kind of limit might be detected here? Something like extreme materialist relativism; while the word "extremophile" (lover of extremes)—which was 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, moreover, that "extremophily" is a relative term.[49] Humans might be imagined as aerophiles, "air-lovers": an extreme from the vantage point of anaerobes. The word "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 "nature" and "society" seem to be pushing against their own and each others' limits.

ASTROBIOLOGY: LIFE FORMS AT THE LIMITS OF DEFINITION

In 1998, NASA founded the Astrobiology Institute, which is distributed across a number of universities and research facilities. Scientists working in astrobiology are dedicated to the study of cosmic biology. They spend time in wet labs

experimenting with extremophiles as analogues to extraterrestrial life. They also look to other worlds 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.'"[50] 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. According to the astrobiologist David Des Marais, a founding challenge presents itself, which 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."[51] This is no simple task, since knowing what is universal is precisely what is to be discovered.

If the Search for Extraterrestrial Intelligence 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 the semiotician 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.

In my conversations with scientists working in astrobiology—enough of a limit biology that most researchers in this field remain based in traditional disciplines (e.g., microbiology, geochemistry)—this question of what would count as a proper *trace* was a live one. 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 (see figure 1.4; also see chapter 7 for a more thorough discussion). Mars meteorite ALH84001, which had been blasted off Mars sixteen million years previous by the impact of another meteorite and arrived on Earth thirteen thousand years ago, harbored elliptical shapes some believed to be outlines of ancient microbial life. David McKay and colleagues, in a 1996 *Science* article entitled "Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001," wrote, "Ovoid features . . . are similar in size and shape to nanobacteria in travertine and limestone. The elongate forms resemble some forms of fossilized filamentous bacteria in the terrestrial fossil record."[52] 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.[53] Their evidence, arrived at by means of electron microscopy, offered a similitude that ended up leaving the object open to criticism. Other astrobiologists were skeptical of pattern-matching recipes for seeing traces of life in ALH84001. Still, advocates' arguments went beyond visual pattern matching; there were also traces

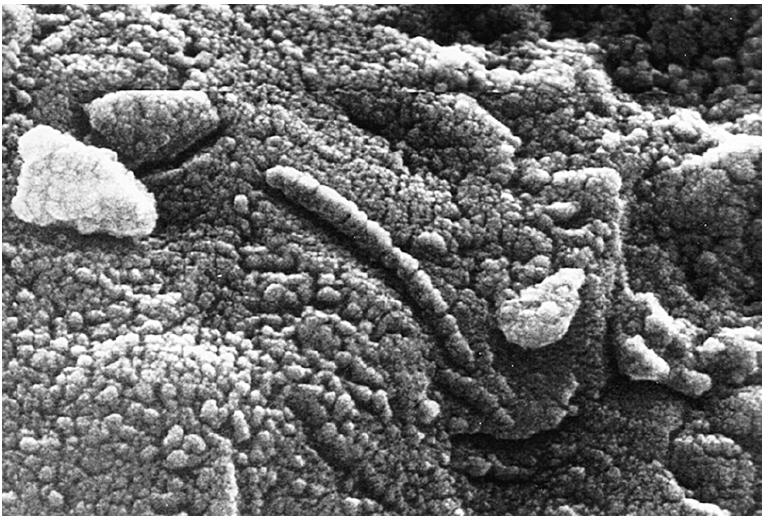

Figure 1.4. Ovoid forms inside Martian meteorite ALH84001, as depicted through scanning electron microscopy. The elongated shape in the center is some several hundred nanometers in length. Discussed in D. S. McKay, E. K. Gibson Jr., et al., "Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001," *Science* 273 (1996): 924–930. Image: NASA.

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.

Objections persisted. Many opponents pointed out that traces on ALH84001 indicated formations two orders of magnitude smaller than any microbe, too cramped to fit within their boundaries all of the apparati cells need to function. 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.

A constant repositioning of what life could be—and the form it might take—is a feature in astrobiological discourse. Some scientists have discussed 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 substantiated and capable of taking a variety of forms not yet known. Such framings are 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 exist many logics from which to reason about extraterrestrial life—from Earth as one planet among others, from organic chemistry, from optics, and more. As Baruch Blumberg has suggested, "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 processes of deduction (as in early vitalist accounts that knew life when they saw it) or induction (as with Darwin, who reasoned, from empirical data, up to what life's processes might be), but also of abduction, which rests on a faith in the intelligibility of future cases (see chapter 2).[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 in its way a secularized supernatural; its orbit extends beyond and embraces our planet, but it also posits a "natural," encountered elsewhere, that can intimate 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. The astrobiologist Paul Davies has 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 to be reinvented constantly.[58] That framing suggests that the "extreme," or "limit," may be a sign not of the ending of biology but rather of its bending toward a political economic purpose.[59] But the form of life in the making is also one that situates Earthly life in 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—the author, fittingly for this essay about limits, of *The Last Dinosaur Book*—wrote in 2003 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 bioterrorism."[61] But against this view, Eduardo Kac and Avital Ronell, in their 2008 book about art in the age of genetic engineering, *Life Extreme*, suggested 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, limits.

The three limit biologies I have examined here are symptomatic of wider processes and discussions in which the "nature" supposed to ground "life" is becoming unstable. They all query "life" 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 presented here make explicit the instability of "life" in such other bioscientifically articulated 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] It marks a limit.

What is a limit? It is the point at which an identity uncouples from itself and shades or snaps into something else. In thinking through limits, I find useful the work of the anthropologists Alberto Corsín Jiménez and Rane Willerslev, who have examined how the Yukaghirs, a hunter-gatherer group in Siberia, think of their two primary hunting economies—elk and sable, which are organized, respectively, around as 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. Corsín Jiménez and Willerslev suggest that, "at the moment of their conceptual *limitation* (the moment when they stand at the end [*fin*] of their worlds, their *de-fining* moment), concepts capture their own shadow and become something other than what they are."[66] Corsín 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."[67] Perhaps that is one of the appeals of the fantastical concept of "life," for as Corsín Jiménez and Willerslev contend, "concepts create their own spaces for expression and . . . draw their own *limits* behind and around their shadows."[68] The limit, they say, "is also the place where the concept out-grows its shadow, and becomes something else."[69] In the examples offered

in this essay, "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."[70]

What is the shadow of life? A first draft answer might be "death"—and a good case could be made that today's biopolitics are ever more entangled with necropolitics. Across a range of work in the anthropology of biomedicine, scholars have examined how "life" and "death" are being redefined in such practices as telesurgery, diagnoses of brain death, organ transplant and trafficking, globalized clinical trails, medical tourism, and transnational circuits of stratified human reproduction.[71] To take one example, in *Life Exposed*, Adriana Petryna examines measures for governing individual and populational life put in place by the Soviet and then Ukrainian governments in the wake of the 1986 Chernobyl nuclear power plant disaster; the lives of people poisoned by radiation have come to be organized—and haunted—by state measures of their "suffering," of, to put it starkly, their proximity to death. Or consider the work of Julie Livingston, who, in her ethnography of an oncology ward in Botswana, shows how "cancer" in that nation-state is not a domain of high-tech chemotherapy but rather of extremes of suppurating and oozing wounds. Peter Redfield's ethnographic monograph, *Life in Crisis*, tracks how the international nongovernmental medical humanitarian organization Doctors without Borders often formalizes "life" as a minimal measurement of nutritional health, operationalizing the organization's ethical mandate to save lives while also often depoliticizing the contexts that distribute life and death chances in the first place.[72] What comes into focus in these works is what Judith Butler has called "precarious life."[73] The notion of a limit biology would look very different if applied to cases such as Petryna's, Livingston's, or Redfield's; what I seek to do in this essay is keyed to the narrower question of how to read ideological pronouncements from academic biology as symptoms of the conceptual instability of "life" today.

A next draft articulation of the question of what the shadow of life is might be this: 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?*[74] That text was dedicated to asking how, after post-structuralism, leftist political concerns with social justice might find moorings in scholarly work. "Theory" had accomplished epistemological labor 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?, where the conferees meditated on "ongoing wars, genocides, epidemics, genomics, life extension technologies, assisted reproduction, pharmaceuticals and potential stem-cell therapeutics" to ask, "How is life 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" seemed, 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 declares that "theory has made us wary of the idea of Life, or indeed any other organicist master-word."[75] 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.[76]

While the limit biologies I have examined emerged well after World War Two, they are contemporary with many crises. And, if anything, in current academic discussions, "life" and "theory" now double, or shadow, one another more densely than ever (with the elongating and warping this implies). At a moment when "life" is at stake in the biopolitics of disaster, human rights, and war, "bio" becomes ungrounded—with Agamben's revival of *zoe*, "bare life," a last-ditch patch, even a refetishizing of the biological.[77] "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 post-post-modern world.[78] "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.

on the Anthropocene Working Group: "The Anthropocene is bad enough. Spare us a Manthropocene," https://twitter.com/KateRaworth/status/522993208650108930; consult http://quaternary.stratigraphy.org/workinggroups/anthropocene/ for more about the working group. For a critical feminist rethinking of how the contemporary geo-historical era might be imagined, see the program of the Anthropocene Feminism conference, held April 10–12, 2014, at the Center for 21st Century Studies (C21) at the University of Wisconsin–Milwaukee: http://c21uwm.com/anthropocene/conference-videos/, keynoted by Elizabeth Povinelli's "Four Figures of the Anthropocene." And see Jussi Parikka, *The Anthrobscene* (Minneapolis: University of Minnesota Press, 2014), which names the "Anthrobscene" as the toxic material accompaniment of computational, tablet, and smartphone media culture, which, far from ushering the contemporary world into a "paperless" ecotopian sublime, fills the world with poisons consequent on producing, consuming, and discarding the devices that permit (some) people to make global assessments at all.

49. Elizabeth Kolbert, "The Lost World: Fossils of the Future," *New Yorker*, December 23 and 30, 2013: 48–56.
50. Timothy Morton, in *Hyperobjects: Philosophy and Ecology after the End of the World* (Minneapolis, MN: University of Minnesota Press, 2013), suggests that processes like climate change are "hyperobjects," entities that exist at scales beyond the capacities of everyday, embodied apprehensions.
51. American Institute of Physics, "Glaciers Sizzle as They Disappear into Warmer Water," American Institute of Physics Newsroom, http://www.newswise.com/articles/glaciers-sizzle-as-they-disappear-into-warmer-water, accessed December 2, 2013.

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6. Gottfried Reinhold Treviranus, *Biologie, oder, Philosophie der lebenden Natur für Naturforscher und Aerzte* (Göttingen, 1802), 16. See also Jean-Baptiste Lamarck, *Recherches sur l'organisation des corps vivants* (Paris, 1802), for a parallel coinage of "biology."
7. Erwin Schrödinger, *What Is Life? The Physical Aspect of the Living Cell* (Cambridge: Cambridge University Press, 1944). Doyle, *On Beyond Living*; Keller, *Refiguring Life*; Kay, *Who Wrote the Book of Life?* See François Jacob, *The Logic of Life: A History of Heredity*, trans. Betty E. Spillmann (New York: Pantheon Books, 1973) for a strong claim about life as a program. See Michael Murphy and Luke O'Neill, eds., *What Is Life? The Next Fifty Years: Speculations on the Future of Biology* (Cambridge: Cambridge University Press, 1995), a commemorative reflection on Schrödinger's legacy. For a contrasting view of life from one of his contemporaries, see J.B.S. Haldane, *What Is Life?* (New York: Boni and Gaer, 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. Lynn Margulis and Dorion Sagan, *What Is Life?* (Berkeley: University of California Press, 1995).
9. A mission statement and program for Cornell's "Futures of Life: Acquiring and Creating Anticipatory Knowledge," sponsored by the university's Department of Science and Technology Studies, was once available at http://www.sts.cornell.edu/Workshop2007/index.htm. Berkeley's "What's Left of Life" conference was once documented at http://whatsleftoflife.org/. What's left of these websites may be found in the Internet Archive: https://archive.org/web/.
10. Michel Foucault, *The Order of Things: An Archaeology of the Human Sciences* (New York: Pantheon Books, 1970). Originally published as *Les Mots et les choses: Une archéologie des sciences humaines* (Paris: Éditions Gallimard, 1966). And see Bruno Latour, "Why Has Critique Run Out of Steam? From Matters of Fact to Matters of Concern," *Critical Inquiry* 30, no. 2 (2004): 225–248. Foucault wrote, "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*" (139). Recent writers on biotechnology are remixing this claim 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: that life itself has been disassembled and revealed to be 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*, 21.
12. Michel Foucault, *The History of Sexuality*, vol. 1: *An Introduction*, trans. Robert Hurley (New York: Vintage, 1978), 143. Originally published as *Histoire de la sexualité*

1: La volonté de savoir (Paris: Éditions Gallimard, 1976). See also Roberto Esposito, "Totalitarianism or Biopolitics? Concerning a Philosophical Interpretation of the Twentieth Century," *Critical Inquiry* 34, no. 4 (2008): 633–644.

13. Stefan Helmreich, *Silicon Second Nature: Culturing Artificial Life in a Digital World* (Berkeley: University of California Press, 1998).
14. Stefan Helmreich, *Alien Ocean: Anthropological Voyages in Microbial Seas* (Berkeley: University of California Press, 2009).
15. Stefan Helmreich, "The Signature of Life: Designing the Astrobiological Imagination," *Grey Room* 23, no. 4 (2006): 66–95.
16. There are many other candidates for limit biologies, not all of them historically new. Take, for example, centuries-old investigations into cryptobiosis, the process through which organisms (such as tardigrades) can deanimate—fully stop their metabolic activity—as they dry out or freeze, only to reanimate much later when conditions are right. Such biologies ask us to consider what tempo and cadence organic processes must possess to count as alive. See Sophia Roosth, "Life, Not Itself: Inanimacy and the Limits of Biology," *Grey Room* 57 (2014): 56–81.
17. For a history of the term "life form," see chapter 2.
18. Quoted in Coleman, *Biology in the Nineteenth Century*, 2. In a 2010 draft of "Modeling, Building, Writing: A History of Nonlinear Dynamics and Complex Systems," his 2012 Harvard University History of Science dissertation, Lambert Williams proposed 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." One might substitute his "difformation" for my deformation and experiment with the results.
19. See Christopher G. Langton, ed., *Artificial Life* (Redwood City, CA: Addison-Wesley, 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, NJ: Princeton University Press, 1991); Sherry Turkle, *Life on the Screen: Identity in the Age of the Internet* (New York: Simon and Schuster, 1995); Lars Risan, *Artificial Life, A Technoscience Leaving Modernity? An Anthropology of Subjects and Objects* (Cand polit. diss., University of Oslo, 1996); Doyle, *On Beyond Living* and *Wetwares*; Helmreich, *Silicon Second Nature*; Alison Adam, *Artificial Knowing: Gender and the Thinking Machine* (London: Routledge, 1998); N. Katherine Hayles, *How We Became Posthuman*; Sarah Kember, *Cyberfeminism and Artificial Life* (London: Routledge, 2003); Chris Kelty and Hannah Landecker. "A Theory of Animation: Cells, L-systems, and Film," *Grey Room* 17 (2004): 30–63; Mitchell Whitelaw, *Metacreation: Art and Artificial Life* (Cambridge, MA: MIT Press, 2004); Jessica Riskin, ed., *Genesis Redux: Essays in the History and Philosophy of Artificial Life* (Chicago: University of Chicago Press, 2007); John Johnston, *The Allure of Machinic Life: Cybernetics, Artificial Life, and the New AI* (Cambridge, MA: Bradford Books/MIT Press, 2008); Robert Geraci, *Apocalyptic AI: Visions of Heaven in Robotics, Artificial Intelligence, and Virtual Reality* (Oxford: Oxford University Press, 2010).
20. Christopher G. Langton, "Toward Artificial Life," *Whole Earth Review* 58 (1988): 74–79, at 74.
21. Quoted in Kevin Kelly, "Designing Perpetual Novelty: Selected Notes from the Second Artificial Life Conference," in *Doing Science: The Reality Club*, ed. John Brockman (New York: Prentice Hall Trade, 1991), 1.

22. Tom Ray, "An Evolutionary Approach to Synthetic Biology: Zen and the Art of Creating Life," *Artificial Life* 1, no. 1/2 (1994): 179–210, at 183, emphasis added.
23. Ray, "An Evolutionary Approach," 184.
24. Susan Oyama, *The Ontogeny of Information,* 27.
25. See Carol Delaney, "The Meaning of Paternity and the Virgin Birth Debate," *Man* 21, no. 3 (1986): 494–513. Such a reading aligns with Hayles's interpretation of an Artificial Life program that was created by evolutionary biologist Richard Dawkins, a program that Hayles argued summoned imagery of a "male programmer mating with a female program to create progeny whose biomorphic diversity surpasses the father's imagination." See N. Katherine Hayles, "Narratives of Evolution and the Evolution of Narratives," in *Cooperation and Conflict in General Evolutionary Processes*, ed. John Casti and Anders Karlqvist (New York: John Wiley & Sons 1994), 125. And see Stefan Helmreich, "The Historical and Epistemological Ground of von Neumann's Theory of Self-Reproducing Automata and Theory of Games," in *Toward a Practice of Autonomous Systems: Proceedings of the First European Conference on Artificial Life*, ed. Francisco Varela and Paul Bourgine (Cambridge, MA: MIT Press, 1992), 385–391.
26. Christopher G. Langton, "Artificial Life," in *Artificial Life*, ed. Christopher G. Langton, (Redwood City, CA, 1989), 2.
27. See Geraci, *Apocalyptic AI.*
28. As I observed in *Silicon Second Nature*, while many people who imagined themselves part of this evolutionary vanguard were at the fringes of their professional fields, many also occupied positions of gender, race, class, and national privilege. Like some of today's synthetic biologists who seek to immortalize themselves by transcribing their names into the DNA sequences of artifactual creatures, many Artificial Life scientists were white American men who fashioned themselves as revolutionary visionaries. Compare Roosth, *Synthetic*, on the scientists J. Craig Venter and George Church, both of whom explicitly seek to immortalize themselves in artificial genomes—and both of whom have also taken to sporting white beards, which, regardless of their intentions, the popular press cannot help but point to as symbols of how these men might be "playing God," where the God in question is the whiskered patriarchal figure of Judeo-Christianity.
29. Karl Sims, "Evolving 3D Morphology and Behavior by Competition," *Artificial Life* 1, no. 4 (1994): 353–372. N. Katherine Hayles, in "Simulating Narratives: What Virtual Creatures Can Teach Us," *Critical Inquiry* 26, no. 1 (1999): 1–26, discusses 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" (6). I find this move reifies "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 gambit surrenders to their rhetoric. Chris Kelty and Hannah 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 in *On Beyond Living* 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 A-Life organisms are themselves reproductions, simulations cut off from any 'essence' of life" (122). More promising than chasing after an essence of "life itself" may be attending to how "liveliness" is a narrative effect; see Natasha Myers, "Modeling Proteins, Making Scientists: An Ethnography of Pedagogy and Visual Cultures in Contemporary Structural Biology," PhD diss., Massachusetts Institute of Technology, 2007.

30. Stefan Helmreich, "'Life is a Verb': Inflections of Artificial Life in Cultural Context." *Artificial Life* 13, no. 2 (2007): 189–201 reviews secondary literature on Artificial Life and also suggests that the present tense transitivity of *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," including the future progressive of *life-as-it-will-be-becoming*.
31. Marilyn Strathern, *Reproducing the Future*.
32. Jean Baudrillard, *Simulations*, trans. from the French by Paul Foss, Paul Patton, and Philip Beitchman (New York: Semiotext(e), 1983).
33. Marilyn Strathern, *After Nature: English Kinship in the Late Twentieth Century* (Cambridge: Cambridge University Press, 1992).
34. See, once again, the *Nature* editorial, "Meanings of 'Life.'" *Nature* 447 (2007): 1031–1032, which 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," 1032.
35. See Bill Curtsinger, *Extreme Nature: Images from the World's Edge* (Pittsburg, CA: White Star, 2005); Mark Carwardine, *Extreme Nature* (New York: Harper Perennial, 2008).
36. W. Ford Doolittle, "Phylogenetic Classification and the Universal Tree," *Science* 284 (1999): 2124–2128, at 2128.
37. Frederic Bushman, *Lateral DNA Transfer: Mechanisms and Consequences* (Cold Spring Harbor, NY: Cold Spring Harbor Laboratory Press, 2002), 2.
38. For recent work on how "race" and singular racial identity as an imagined "biogenetic" category is fracturing in the days of genetic genealogy, as people search for "ancestrally informative" portions of DNA and find instead a maze of possible ancestral identifications, see Whitmarsh and Jones, eds., *What's the Use of Race*; Wailoo, Nelson, and Lee, eds., *Genetics and the Unsettled Past*; Nadia Abu Al-Haj, *The Genealogical Science*.
39. Eric Bapteste, Yan Boucher, Jessica Leigh, and W. Ford Doolittle, "Phylogenetic Reconstruction and Lateral Gene Transfer," *Trends in Microbiology* 12, no. 9 (2004): 406–411, at 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" (409).
40. See Miguel García-Sancho, *Biology, Computing, and the History of Molecular Sequencing: From Proteins to DNA, 1945–2000* (Basingstoke, UK: Palgrave Macmillan, 2012) and Hallam Stevens, *Life Out of Sequence: A Data-Driven History of Bioinformatics* (Chicago: University of Chicago Press, 2013).
41. Adrian Mackenzie, "Bringing Sequences to Life: How Bioinformatics Corporealizes Sequence Data," *New Genetics and Society* 22, no. 3 (2003): 315–332. For an

ethnographic account of how this instability shapes notions of the normal and pathological, see Carlo Caduff, "The Semiotics of Security: Infectious Disease Research and the Biopolitics of Informational Bodies in the United States," *Cultural Anthropology* 27, no. 2 (2012): 333–357.

42. The phrase is from Brian Cantwell Smith, *On the Origin of Objects* (Cambridge, MA: MIT Press, 1996).
43. 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" (*Modest_Witness*, 225).
44. For a cultural analysis of this practice, see Adrian Mackenzie, Claire Waterton, Rebecca Ellis, Emma K. Frow, Ruth McNally, Lawrence Busch, and Brian Wynne, "Classifying, Constructing, and Identifying Life: Standards as Transformations of 'The Biological,'" *Science, Technology, & Human Values* 38, no. 5 (2013): 701–702.
45. Fernando de la Cruz and Julian Davies, "Horizontal Gene Transfer and the Origin of Species: Lessons from Bacteria," *Trends in Microbiology* 8, no. 3 (2000): 128–133, at 128.
46. Venter, on Voice of America's "Our World," March 17, 2007, transcript at http://www.voanews.com/content/a-13–2007–03–16-voa3–66542687/554255.html, accessed January 5, 2015.
47. Sallie W. Chisholm "*Prochlorococcus*: How to Dominate the Oceans with 2000 Genes," Biological Engineering Seminar Series, Massachusetts Institute of Technology, Cambridge, MA, 22 April 2004.
48. Francisco Varela, *Principles of Biological Autonomy*. The North-Holland Series in General Systems Research, Vol. 2 (New York: Elsevier North-Holland, 1979), 13. One might also call it, following a recent coinage of Scott Gilbert, *symbiopoiesis*. See Scott F. Gilbert, Emily McDonald, Nicole Boyle, Nicholas Buttino, Lin Gyi, Mark Mai, Neelakantan Prakash, and James Robinson, "Symbiosis as a Source of Selectable Epigenetic Variation: Taking the Heat for the Big Guy," *Philosophical Transactions of the Royal Society*, B 365(1540)(2010): 671–678.
49. Robert D. Macelroy, "Some Comments on the Evolution of Extremophiles," *Biosystems* 6 (1974): 74–75. For analysis of this rhetorical move, see Stefan Helmreich, "Extraterrestrial Relativism," in Debbora Battaglia, David Valentine, and Valerie Olson, eds., special section, "Extreme: Humans at Home in the Cosmos," *Anthropological Quarterly* 85, no. 4 (2012): 1127–1141.
50. David S. McKay, Simon Clemett, Kathie L. Thomas-Keprta, and Everett K. Gibson, "The Classification of Biosignatures," Abstract 12873, NASA Astrobiology Institute General Meeting, February 10–12, 2003, Tempe, AZ, *Astrobiology* 2, no. 4 (2002): 625–626.
51. David J. Des Marais, Martin O. Harwit, Kenneth W. Jucks, James F. Kasting, Douglas N.C. Lin, Jonathan I. Lunine, et al., "Remote Sensing of Planetary Properties and Biosignatures on Extrasolar Terrestrial Planets," *Astrobiology* 2, no. 2 (2002): 153–181, at 154.
52. David D. McKay, Everett K. Gibson, Jr., Kathie L. Thomas-Keprta, Hojatollah Vali, Christopher S. Romanek, et al., "Search for Past Life on Mars: Possible Relic Biogenic Activity in Martian Meteorite ALH84001," *Science* 273 (1996): 924–930, at 928.
53. McKay et al., "Search for Past Life on Mars," 929.

54. Baruch S. Blumberg, "The NASA Astrobiology Institute: Early History and Organization," *Astrobiology* 2, no. 3 (2003): 463–470, at 470.
55. Or, perhaps, *revelation*. The Vatican has taken a keen 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, read Sarah Kember, "Media, Mars and Metamorphosis," *Culture Machine* 11 (2010): 31–40.
56. Abduction need not refer only to cases from the future. Abduction can also refer to possible future *knowledge* of the past—as, for example, about a revealed or repudiated ancestor. See Stefan Helmreich, "Induction, Deduction, Abduction, and the Logics of Race and Kinship: Commentary on Stephan Palmié's "Genomics, Divination, 'Racecraft,'"" *American Ethnologist* 34, no. 2 (2007): 228–230.
57. Paul Davies, "Searching for Multiple Origins of Life," in Program, Study Week on Astrobiology, November 6–10, 2009, Vatican City, 2009, 10.
58. Cooper, *Life as Surplus.*
59. Such an account would view "biological theory" as an effect of capital, much as Terry Eagleton saw "theory" as a cultural production of capital, though one that, as a fragment of "culture," inherited a demand to be reflexive about its conditions of emergence. See Terry Eagleton, *After Theory* (New York: Basic Books, 2003). Look to Steven Knapp and Walter Benn Michaels, "Against Theory," *Critical Inquiry* 8, no. 4 (1982): 723–742, for a caution against claims of this sort.
60. See Valerie Olson, "The Ecobiopolitics of Space Medicine," *Medical Anthropology* 29, no. 2 (2010): 170–193.
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: University of Chicago Press, 2003), xiii. See also Mariam Fraser, Sarah Kember, and Celia Lury, "Inventive Life: Approaches to the New Vitalism," *Theory, Culture & Society* 22, no. 1 (2005): 1–14.
62. Eduardo Kac and Avital Ronell, *Life Extreme: An Illustrated Guide to New Life* (Cambridge, MA: Dis Voir, 2008), 13.
63. See Sophia Roosth, "Biobricks and Crocheted Coral: Dispatches from the Life Sciences in the Age of Fabrication," *Science in Context* 26, no. 1 (2013): 153–171.
64. See Raymond Williams, *Keywords: A Vocabulary of Culture and Society* (New York: Oxford University Press, 1976). And see Fischer, *Emergent Forms of Life* for a claim about a contemporary crisis of meaning in the life sciences.
65. Alberto Corsín Jiménez and Rane Willerslev, "'An Anthropological Concept of the Concept': Reversibility among the Siberian Yukaghirs," *Journal of the Royal Anthropological Institute* 13: 527–544. See also Marilyn Strathern, "Sharing, Stealing and Borrowing Simultaneously," in *Ownership and Appropriation*, ed. Veronica Strang and Mark Busse (Oxford: Berg, 2011), 23–42.
66. Corsín Jiménez and Willerslev, "Anthropological Concept," 538. Corsín Jiménez and Willerslev ask 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" (537).

67. Ibid., 528.
68. Ibid., 537.
69. Ibid., 538.
70. 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, John S. McCaskill, Norman H. Packard, and Steen Rasmussen, "Living Technology: Exploiting Life's Principles in Technology," *Artificial Life* 16, no. 1 (2010): 89–97.
71. Lock, *Twice Dead*; João Beihl, *Vita: Life in a Zone of Social Abandonment* (Berkeley: University of California Press, 2005); Adriana Petryna, *When Experiments Travel: Clinical Trials and the Global Search for Human Subjects* (Princeton, NJ: Princeton University Press, 2009); Erica Caple James, *Democratic Insecurities: Violence, Trauma, and Intervention in Haiti* (Berkeley: University of California Press, 2010); Vinh-Kim Nguyen, *The Republic of Therapy: Triage and Sovereignty in West Africa's Time of AIDS* (Durham, NC: Duke University Press, 2010); Elizabeth Povinelli, *Economies of Abandonment: Social Belonging and Endurance in Late Liberalism* (Durham, NC: Duke University Press, 2011); Joseph Dumit, *Drugs for Life: How Pharmaceutical Companies Define Our Health* (Durham, NC: Duke University Press, 2012); Didier Fassin, *Humanitarian Reason: A Moral History of the Present* (Berkeley: University of California Press, 2012); Hamdy, *Our Bodies Belong to God*; Julie Livingston, *Improvising Medicine: An African Oncology Ward in an Emerging Cancer Epidemic* (Durham, NC: Duke University Press, 2012); Anne Pollock, *Medicating Race: Heart Disease and Durable Preoccupations with Difference* (Durham, NC: Duke University Press, 2012); Rachel Prentice, *Bodies in Formation: An Ethnography of Anatomy and Surgery Education* (Durham, NC: Duke University Press, 2013); S. Lochlann Jain, *Malignant: How Cancer Becomes Us* (Berkeley: University of California Press, 2013); Alice Street, *Biomedicine in an Unstable Place: Infrastucture and Personhood in a Papua New Guinea Hospital* (Durham, NC: Duke University Press, 2014). For a multispecies account of the entanglement of biopolitics and necropolitics, see Emily Mannix Wanderer, "Biologies of Betrayal: Judas Goats and Sacrificial Mice on the Margins of Mexico," *Biosocieties* 10, no. 1 (2015): 1–23.
72. Peter Redfield, *Life in Crisis: The Ethical Journey of Doctors without Borders* (Berkeley: University of California Press, 2013).
73. Judith Butler, *Precarious Life: The Powers of Mourning and Violence* (New York: Verso, 2004).
74. Judith Butler, John Guillory, and Kendall Thomas, *What's Left of Theory? New Work on the State and Politics of Literary Theory* (London: Routledge, 2000).
75. John Schad, "Epilogue: Coming Back to 'Life,'" in *Life.After.Theory*, ed. Michael Payne and John Schad (London: Bloomsbury Academic, 2003), 172.
76. Schad, "Epilogue," 175–176.
77. Giorgio Agamben, *Homo Sacer: Sovereign Power and Bare Life*, trans. from the Italian by Daniel Heller-Roazen (Stanford, CA: Stanford University Press, 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. See Donna Haraway, "A Cyborg Manifesto: Science, Technology, and Socialist-Feminism in the

Late Twentieth Century," in *Simians, Cyborgs, and Women: The Reinvention of Nature* (New York: Routledge, 1991), 149–182, at 150.

78. 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, etc.; see Peter Galison, "Specific Theory," *Critical Inquiry* 30, no. 2 [2004]: 379–383), astrobiology-minded cosmologists in 2010 leapt on beyond the universal into the *metaversal*: the physicists Alejandro Jenkins and Gilad Perez argued in *Scientific American* 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 (Alejandro Jenkins and Gilad Perez, "Looking for Life in the Multiverse," *Scientific American* 302, no. 1 [2010]: 42–49, 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, no. 2 (2004): 324–335, and Derek Attridge and Jane Elliott, eds., *Theory After 'Theory'* (London: Routledge, 2011). See also Elizabeth Weed and Ellen Rooney, eds., "What's the Difference? The Question of Theory," special issue, *differences: A Journal of Feminist Cultural Studies* 21, no. 1 (2010) and Grant Farred and Michael Hardt, eds., "Theory Now," special issue, *South Atlantic Quarterly* 110, no. 1 (2011).

CHAPTER 2: LIFE FORMS

1. Committee on the Limits of Organic Life in Planetary Systems and Committee on the Origins and Evolution of Life, *The Limits of Organic Life in Planetary Systems* (Washington, DC: National Research Council, 2007).
2. Ibid., viii.
3. Henri Focillon, *La vie des formes* (Presses Universitaires de France, 1934), trans. Charles B. Hogan and George Kubler as *The Life of Forms in Art* (Cambridge, MA: MIT Press, 1989), 34.
4. Charles S. Peirce, *The Essential Peirce: Selected Philosophical Writings*, vol. 2 (1893–1913), ed. the Peirce Edition Project (Bloomington: Indiana University Press, 1998), 299. See also Richard Doyle, *Wetwares: Experiments in Postvital Living* (Minneapolis: University of Minnesota Press, 2003), 25.
5. Raymond Williams, *Keywords: A Vocabulary of Culture and Society* (New York: Oxford University Press, 1976), 15.
6. Stefan Helmreich, *Silicon Second Nature: Culturing Artificial Life in a Digital World* (Berkeley: University of California Press, 1998) and *Alien Ocean: Anthropological Voyages in Microbial Seas* (Berkeley: University of California Press, 2009). Sophia Roosth, "Biobricks and Crocheted Coral: Dispatches from the Life Sciences in the Age of Fabrication," *Science in Context* 26, no. 1 (2013): 153–171, *Synthetic: How Life Got Made* (Chicago: University of Chicago Press, forthcoming).