Introduction

IN THE BEGINNING, Tom Ray created Tierra, an elementary computer model of evolution. Laboring late into the night in early January 1990, Ray released a single self-replicating program into a primordial information soup he had programmed, producing what he would come to call a computational "ecosystem" in which "populations" of "digital organisms" could "evolve." Ray happily extended words associated with life to this "artificial world" because he defined evolution as the story of the differential survival and replication of information structures. For Ray and many others in the nascent scientific field of Artificial Life, computer programs that self-replicate—like computer viruses—can be considered new forms of life, forms that can be quickened into existence by scientists who view the computer as an alternative universe ready to be populated with reproducing, mutating, competing, and ultimately unpredictable programs.

On July 7, 1994, some four years after Tierra's nativity, Ray spoke to a large audience of computer scientists, biologists, and engineers at a Massachusetts Institute of Technology (MIT) conference on Artificial Life. He suggested that the digital organisms in Tierra needed more space to evolve. He proposed that Tierra be expanded, that people using computer networks around the world volunteer to accept a franchise of the system, that they give a portion of their Internet accounts over to running Tierra as a "low-priority background process," that Tierra—Spanish for "Earth"—become coextensive with our planet. Ray wanted the habitat of Tierran organisms to be jacked up from a single computer memory to the memories of many machines the world over, from a space the informatic equivalent of a drop of water to one the equivalent of a small pond. Ray's talk, "A Proposal to Create a Network-Wide Biodiversity Reserve for Digital Organisms," was impassioned, almost evangelical. As he paced the stage, Ray explained that the Tierran ecology could only really blossom if it could be expanded into global cyberspace. Only in this way might there be anything analogous to the Cambrian explosion of diversity in the organic world, only in this way might self-replicating computer programs evolve into software creatures that might be harvested, domesticated, and bred for potentially useful applications. Ray's vision was spectacular: he hoped that Tierran organisms could "roam freely" in a cyberspace reserve, traveling around the globe in search of spare central processing unit (CPU) cycles, likely following nightfall as cycles were freed up by humans logging off for the day. Ray stopped pacing and said, "I think of these things as alive, and I'm just trying to figure out a place where they can live." He mentioned a parallel project to consolidate a nature reserve in Costa Rica, where he began his career as a tropical ecologist: "I'm doing the same thing in the tropical rain forest. I sort of see these two projects as conceptually the same." Ray's conviction that he had authored a new instance of life motivated his pleas to the audience to participate in his project, to, as he put it repeatedly, "give life a chance."

Ray was not alone in his belief that he had created life in a computer. The MIT conference was populated by many scientists who believed that programs could count as life-forms, or, at the very least, as models of life-forms. Just a few hours after Ray's talk, researchers gathered in a capacious computer simulation demonstration hall, where they moved in flocks from one computer screen to the next, waiting for the expectant scientist stationed at each machine to say something about the artificial world he or she had created. Behind the glowing glass screens of Macintoshes, Sun Sparcstations, and Silicon Graphics Iris workstations hovered images of colorful artificial fish, pictures of roving two-eyed Ping-Pong ball–shaped creatures, and odd triangular and trapezoidal figures that chased each other around on a planar surface. Through some screens researchers could look down over imaginary landscapes where shifting patterns of dots represented populations of elementary organisms competing over territory and resources. A few simulations presented the viewer only with ever-updating graphs of population statistics for self-replicating programs.

Most simulations were designed for didactic and experimental purposes, as illustrations or abstract models of the dynamics of evolution and lifelike behavior in populations. Such artifacts often consisted of large programs containing packs of smaller self-replicating programs meant to represent populations of real creatures, such as ants, rabbits, or mosquitoes. Artificial Life researchers dedicated to these sorts of models were convinced that through distilling the logic of evolution in a computer, they might hatch ideas for a theoretical biology that could account for both real and possible life. Some other scientists, like Ray, went beyond such modest claims, maintaining that computer processes exhibiting suitably lifelike behavior could be considered new instances of life itself. They said that their self-reproducing algorithms were *real* artificial life-forms; no mere representations or counterfeits of life, these algorithms were artifactual creatures ultimately realized as material entities in the voltage patterns deep within computers. Researchers responsible for these sorts of programs hoped that through creating swarms of self-replicating entities in a virtual universe, they might add to the dominion of life a new kingdom of organisms existing in the universe of cyberspace.

The claims of some Artificial Life researchers to have synthesized life may sound strikingly novel, but they also mutate a well-rooted historical tradition of attempting to manufacture living things, a tradition that entwines activities that have been variously mystical, literary, religious, technological, and scientific. The Pygmalion myth tells of a sculptor who made an ivory statue, Galatea, with which he fell hopelessly in love, and which, with the help of Venus, he brought to life with a kiss. Talmudic lore tells of a Rabbi Löw of Prague who, in 1580, fashioned a creature of clay called the Golem, which he brought to life by breathing into its mouth the ineffable name of God, an act that appropriated the divine creative power of the Word. Mary Shelley's *Frankenstein* (1818) famously sets forth the tale of a jigsaw creature jolted to life with electricity. Shelley cast Doctor Frankenstein as a modern Prometheus, that figure in Greek mythology who stole fire from the gods and created humanity from wet earth. In *Faust*, Goethe wrote of a young student who made a little man in a vial, a creature whose first words enunciate some of the themes of unnatural fatherhood and supernatural fear that have attended the quest for artificial life. The homunculus speaks to his creator from behind a glass barrier prefiguring the computer screens that separate Artificial Life programmers from their creations:

HOMUNCULOUS (*speaking to Wagner from the phial*).
Well, Father, what's to do? No joke I see.
Come, take me to your heart, and tenderly!
But not too tight, for fear the glass should break.
That is the way that things are apt to take:
The cosmos scarce will compass Nature's kind,
But man's creations need to be confined.
Goethe 1832:101

In these fanciful tales, life is synthesized through a sort of masculine birthing, a reproduction with no need for women's bodies, a reproduction that brings inert matter to life with a kiss, a breath, a word, a spark.

Synthetic life has been a grail for scientific theory and practice as well. Using the technology of clockwork mechanism in place of more archaic hydraulic and pneumatic techniques, people built a variety of automata during the Renaissance and the Enlightenment, the most famous of which played music or mimicked animal behavior. In 1748, Julien Offray de La Mettrie, in his *L'Homme machine*, argued against René Descartes's separation of mind and body and declared that all aspects of human vitality could be mechanized. In 1872, Samuel Butler reasoned in his book *Erewhon* that Darwinism conceived organisms as machines, opening up the possibility of machine life and evolution. By 1948, Norbert Wiener, a founding figure in cybernetics, was able to theorize animals and machines as kindred kinds of information-processing devices. Working on allied notions at around the same time, the mathematician John von Neumann proposed that machines hosting stored programs might be capable of reproducing themselves if such programs contained self-descriptions (Watson and Crick's later explanation of DNA's structure and function in 1953 in fact used the rhetoric of programming to suggest that DNA was a coded self-description folded up in organisms). In 1956, computer scientists gathered at Dartmouth University to establish the field of Artificial Intelligence, an endeavor aimed at making minds out of computers. A rich history has prepared the way for Artificial Life to make sense.

Tom Ray's research builds on this history. And at the MIT Artificial Life conference, Ray was a figure of some importance, recognized as one of the first to have successfully put together a simulation of evolution, to have moved fully from a view of the computer as substitute mind to one envisioning it as a surrogate world. His affiliation with the Santa Fe Institute for the Sciences of Complexity, a research center in Santa Fe, New Mexico, devoted to the computer simulation of nonlinear phenomena, also gave his words a certain weight. The Institute is widely known as a site for innovative work in complexity science and as an epicenter of Artificial Life research. Ray's talk was much anticipated and his own excitement about his project was indexed by the mantric, John Lennon-like "give life a chance" chorus that punctuated his talk and that tagged him as part of a generation of 1960s and 1970s young adults grown into 1990s scientists.

Ray's injunction echoed off the walls of the lecture hall as I readied myself for my turn on stage. I had come to this conference as an anthropologist fascinated with the practices of Artificial Life and had just flown in from New Mexico, where I had finished up a year of fieldwork at the Santa Fe Institute. As I moved toward the podium, my life in Santa Fe flashed before me in an Adobe Photoshop blur. I remembered interviews with scientists arguing passionately that, yes, computers are alternative universes in all senses that matter; that, yes, life really is just information processing; and that, yes, evolution has selected an elite corps of computer scientists to facilitate its phase transition from carbon to silicon. But by now the story I had become interested in telling about Artificial Life was not one that celebrated it as some transcendent next evolutionary step. Rather, it was an anthropological tale, one interested in how people have come to think of computer programs as lifeforms and one curious about the practical, institutional, cultural, political, and emotional dimensions of Artificial Life work. It was a tale aimed at understanding how Artificial Life might herald new conceptions and configurations of the natural, the artificial, and the organic in late-twentieth-century U.S. and European culture. It was a story about the changing meaning of "life."

And it was a story I started to tell at this conference, which marked the conclusion of my extended fieldwork among Artificial Life scientists and the beginning of the process of writing this book, which is an ethnographic portrait of the Artificial Life community, especially that segment located at the Santa Fe Institute. Because the Artificial Life community extends beyond the Institute into a network of universities around the United States and Europe, this book also reports on interviews I carried out over electronic mail and on fieldwork I did at international conferences. Before I descend into the anthropological account that my fieldwork produced, though, let me rewind to locate Artificial Life on the scientific map, to say more about the field's origins, mission, institutional contexts, and technological attachments. Let me also set my own theoretical and methodological frames in place.

ARTIFICIAL LIFE

Artificial Life is a field largely dedicated to the computer simulation—and, some would ambitiously add, synthesis in real and virtual space—of biological systems. It emerged in the late 1980s, out of interdisciplinary conversations among biologists, computer scientists, physicists, and other scientists. Artificial Life researchers envision their project as a reinvigorated theoretical biology and as an initially more modest but eventually more ambitious enterprise than Artificial Intelligence. Whereas Artificial Intelligence attempted to model the mind, Artificial Life workers hope to simulate the life processes that support the development and evolution of such things as minds. They plan to capture on computers (or, sometimes, in autonomous robots) the formal properties of organisms, populations, and ecosystems. A mission statement on Artificial Life generated by the Santa Fe Institute summarizes the approach:

> Artificial Life ("AL" or "ALife") studies "natural" life by attempting to recreate biological phenomena from first principles within computers and other "artificial" media. Alife complements the analytic approach of traditional biology with a synthetic approach in which, rather than studying biological phenomena by taking apart living organisms to see how they work, researchers attempt to put together systems that behave like living organisms. Artificial life amounts to the practice of "synthetic biology." (Santa Fe Institute 1994b:38)

The conceptual charter for this practice of synthesizing new life is captured by the Artificial Life scientist Christopher Langton's declaration that life "is a property of the *organization* of matter, rather than a property of matter itself" (Langton 1988:74). Some have found this claim so compelling that they maintain that alternative forms of life can exist in computers, and they hope the creation of such life-forms can 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 (Langton 1989:1). Although Artificial Life remains peripheral to mainstream biology, researchers are attempting to build institutional and interdisciplinary alliances, and they have generated enthusiasm among a few prominent figures in evolutionary biology.

The field was officially named in 1987, when Langton, then a post-doctoral fellow at Los Alamos National Laboratories, in Los Alamos, New Mexico, hosted a conference to explore how computers might be used to model biological systems. Langton gathered a group of people that included computer scientists, biologists, physicists, and philosophers, and he took the opportunity to christen this new field "Artificial Life," a move that would have a great impact on how the field would be advertised, organized, and historically situated as well as on how people would craft cross-disciplinary and international ties. One person summarized the move to me thus: "Artificial Life is an excellent phrase. It provokes attention. Without the phrase there would be no field of research, of that I am convinced." One young scientist interested in using simulations to model problems in animal and human evolution said to me, "I think, as a term, 'artificial life' is a stroke of advertising genius. A research field is a product that scientists market to governmental funding agencies, to prospective students, and to the general public. The more evocative the name, the better exposure the field gets. The name might not mean much formally, but its poetic power is undeniable." In the late 1980s and early 1990s, Artificial Life became a magnetic topic in popular science journalism because of its spectacular promises of creating new life and because its name suggested it as a successor to Artificial Intelligence. One older scientist, not centrally interested in Artificial Life, complained to me about the grandness of the name: "What an ill-defined subject, Artificial Life. A silly name. We live in an age of soundbites." Soundbites, however, can often become nutrients for serious research projects. At the end of the 1980s, Artificial Life became one of the research foci of Los Alamos's nearby relative, the Santa Fe Institute for the Sciences of Complexity.

In its literature, the Santa Fe Institute describes itself as a "private, independent organization dedicated to multidisciplinary scientific research and graduate education in the natural, computational, and social sciences" (Santa Fe Institute 1991:2).[1] Since its founding in 1984 by a confederation of older scientists working mostly at Los Alamos, the Institute has become a gathering ground for an international community interested in "complexity" and nonlinear dynamics in physical, chemical, biological, computational, and economic systems. The Institute regularly sponsors interdisciplinary workshops and serves as a central node in many research networks, and it has been instrumental in organizing the

U.S. conferences on Artificial Life that have made the field a going concern. The Institute is unique as a scientific research center in that the only scientific devices in evidence are the many computers on which people do the work of simulating complex systems. It is the use of simulation as a common tool that facilitates the interdisciplinary interactions the Institute is so interested in fostering. Like Artificial Life, the Santa Fe Institute has received a good deal of celebratory press and has been featured in many popular science forums including *Discover, Omni, Science,* and the *New York Times.*

The Santa Fe Institute is only one of several sites around the world where work in Artificial Life is conducted, or, perhaps more accurately, where computer modeling of biological systems is done. This activity has been under way in many places for quite some time.[2] A good portion of Artificial Life work has to do with developing robots that act autonomously and adaptively and that employ control systems developed using insights from evolution. In this book, I focus most sharply on the use of computer simulations to model and create "artificial worlds": virtual, alternative, sites for evolution.[3] I am concerned with simulation approaches partly because they predominated at Santa Fe, but also because they carry the view of life as information processing to its most vivid conclusion. Simulation also ushers scientific practice and theory into new epistemological territory, territory that reshapes how scientists think about the fit between theory and experiment and between representation and reality.

Not all Artificial Life scientists are happy with how the recent history of the field is told, with how this shapes the terrain of inquiry, or with how the Santa Fe Institute is privileged in popular accounts (particularly in Levy 1992b; Lewin 1992; Waldrop 1992; Kelly 1994; Turkle 1995). Many Europe-based researchers argue that Artificial Life was not created ex nihilo in New Mexico but has descended from tangled international lineages of cybernetics, systems theory, Artificial Intelligence, self-organization theory, origins of life research, and theoretical biology. The Chilean-born and Paris-based biologist Francisco Varela, known for his theoretical work in cognitive science and immunology, has been quite vocal about this (see Varela 1995). He has argued that the materialization of Artificial Life in New Mexico has focused attention on overly computational views of life and that the naming of Artificial Life on the analogy to Artificial Intelligence has only made this more intense. U.S. narrations of Artificial Life history are notorious in the international community for their erasure or marginalization of European and Latin American precedents and scientists, of transnational collaborations, and of the social, intellectual, and economic contexts that produced the science in some places and not others. Indeed, my own decision to do fieldwork on the community at Santa Fe was powerfully guided by readings of popular science, and this book runs the risk of reinforcing the mainstream myth that "Artificial Life was born out of Zeus' head in Santa Fe, New Mexico, in the 1980s"—as one Europe-based scientist sardonically summarized it to me.[4]

CULTURING ARTIFICIAL LIFE

Artificial Life is more than a new way of thinking about biology. It is a symptom and a source of mutating visions of "nature" and "life" in an increasingly computerized world. As such, it has a social, cultural, and historical specificity. This book is concerned with chasing down that specificity. I document how the local knowledges and artifacts of Artificial Life are produced in the institutional and imaginative spaces of the Santa Fe Institute and in the clusters of computer simulation that it holds in its orbit. My argument is that Artificial Life scientists' computational models of "possible biologies" are powerfully inflected by their cultural conceptions and lived understandings of gender, kinship, sexuality, race, economy, and cosmology and by the social and political contexts in which these understandings take shape. Ideas and experiences of gender and kinship circulating in the heterosexual culture in which most researchers participate, for example, inform theories about "reproduction," "sex," "relatedness," and "sexual selection" in artificial worlds, and notions of competition and market economics in the capitalist West shape the construction of "artificial ecologies" in which populations of programs vie to "survive" and "reproduce."

"Silicon second nature" is my name for the substance and space that Artificial Life researchers seek to create in computers. The concept of second nature has a lineage traceable to Hegel, who "taught us to see a difference between 'first nature'—the given, pristine, edenic nature of physical and biotic processes, laws, and forms—and 'second nature.' Second nature comprises the rule-driven social world of society and the market, culture and the city, in which social change is driven by a parallel set of socially imposed laws"(Smith 1996:49). Artificial Life worlds are second natures in that they are rule-ordered human constructions, but also in that they are meant to mirror first nature. And they are second natures in still another way: they not only ape first nature but also offer to replace it, to succeed it as a resource for scientific knowledge. Second nature, of course, also refers to human habits and cultural practices that, through repetition, come to seem rooted in organic common sense. As Artificial Life researchers embrace the logics of synthetic vitality, they come to possess a new sort of subjectivity, a silicon second nature that may be increasingly common among humans inhabiting a world in which computers are haunted by "life."

This does not mean that the configurations precipitating from the solutions of Artificial Life are entirely new. Artificial life and artificial worlds are cultured in a social medium located in the powerful history of Western technoscience. More often than not, the first nature that sits as a model for silicon second nature is marked by images of creation, individuals, lineages, families, economies, and communities resonant with the values and practices of white middle-class people in secularized Judeo-Christian cultures in the United States and Europe. Of course, clean lines cannot be drawn from the demographic profile of the Artificial Life community to ideologies or imagery encoded in their computational work. It is messier than that. But not so complex that regularities cannot be discerned. I am interested in "hegemonic" rather than neatly "ideological" stories, in stories that find sustenance in pervasive commonsensical, almost unconscious, dominant ways of understanding, experiencing, and acting in the world (see Gramsci 1971; Williams 1977; Comaroff and Comaroff 1991). I am not always or solely concerned with the motives of Artificial Life researchers. In looking at imagery encoded in simulations, I follow the feminist theorist Carol Cohn, who has argued that "individual motivations cannot necessarily be read directly from imagery; the imagery itself does not originate in these particular individuals but in a broader cultural context" (1987:693).

This is not to say that people's motives are unimportant—at many moments I *am* concerned with researchers' stated inspirations—only that they are not the whole story. Because much of this book is devoted to analyses of simulations, I tend to foreground the role of cultural narratives in rendering Artificial Life artifacts legible to the scientific communities that consume them. I assume that science, while institutionally and discursively set apart from other human practices, crucially intersects with and is fundamentally constituted by ostensibly nonscientific activities and ideas. Following the anthropologist Marilyn Strathern, I understand "culture" to consist in part "in the way people draw analogies between different domains in their worlds" (1992b:47). The practice of Artificial Life is fully cultural in this sense; different domains—cultural and scientific, natural and artificial—are drawn together to create new ways of theorizing life. Twisting Chris Langton's formulation to my own purposes, I contend that constructions of *life-as-it-could-be* are built from culturally specific visions of *life-as-we-know-it*.

The logic of Artificial Life promises to transform the texture of our everyday experience of machines and programs. We already encounter computers as beyond our comprehension, as animated by logics that make them opaque, even uncanny. The Internet and World Wide Web, both important for the dissemination of Artificial Life research, are thickly grown over with organic metaphors. No longer symbols of bureaucratic rationality, computers, in the age of personal and networked computing, have become more "natural" to use. The *Whole Earth Review*, a magazine that in the wake of the 1960s extolled the virtues of getting back to the land through cooperative gardening, now advocates getting on the Internet as a way of rediscovering organic community. The modem has replaced the hoe as the technology of reunion with nature. In an age of environmentalism, it is no wonder that biodiversity appears online in Ray's global reserve for digital organisms. The cyberspace first envisioned in the science fiction of William Gibson has gone green.

Artificial Life technology is a kind of time machine signaling a quest to re-create nature in the image of a communication and control device devoted to information processing. Tierra offers us the opportunity to travel back to the dreamtime of the Cambrian period, back to an idyllic past full with possibility. Tierran organisms are not unlike the dinosaurs cinematically resurrected in *Jurassic Park*. Both are avatars of a digital nature produced through the magic of informatics. And this digital nature germinates in the circuits of more computers than those used in Artificial Life or in the Military Industrial Light and Magic Complex, Julian Bleecker's name for the closely related collection of Defense Department and Hollywood imaging technologies. The Human Genome Project, the multibillion-dollar transnational enterprise of mapping the full complement of human genes and of sequencing the billions of base pairs that compose human chromosomes, catapults human nature, written in the code of information, into databases that may increasingly define what counts as human being. The sequence map is often figured explicitly as a holy grail for biology (see Flower and Heath 1993), keying us into the themes of salvation history that inhabit informatics and molecular genetics at the turn of the second Christian millennium. As Artificial Life scientists remake the organism and replay the creation, they run their time machines forward as well as backward; like people who have their bodies frozen in the hope of future reanimation, Artificial Life researchers seek to wake their creations up in new but familiar worlds. When *Jurassic Park* daydreams are downloaded into computers, we often get resuscitations of Judeo-Christian creation stories, masculine self-birthing narratives, heterosexual family values, and utopian visions of a cyberspace capable of returning us to an Edenic world of perfect communication and commerce. In short, we get digitized nature programs about endangered fantasies. And we frequently get them with an environmentalist twist that reaches back to a 1960s countercultural sensibility. John Lennon, recently reborn as a computer-manipulated audio ghost, inspirits the newly reunited Beatles no less than he does the ecologically correct refrains of Tom Ray, one of a number of scientists who see Artificial Life as reviving countercultural promises to radically remake the way we see life and the universe. Artificial Life is a way of life in these digital days, and vital signs are routinely animated via computer. All of this doubling and déjà vu is oddly appropriate at this fin de siècle, as the year 2000 promises second chances and new and improved beginnings (see Schwartz 1996). The future has arrived just in time, and the fashioning of vitality as information processing—as the replication of code—has already brought us a kind of second coming in the flesh and blood of the lamb clone Dolly, who appears in the aftermath of nuclear DNA transfer, not nuclear war, and whose genes have been forced to reveal their essence as programs for self-duplication. Artificial Life joins cloning and cryonics in a trinity of millennial technologies of resurrection.

As organic logic is injected into computation, some of us may come to understand computers as effective because they operate using "natural" principles. At the same time, we may come to see the natural world embodying a computational calculus. The cultural commitments embedded in such visions may become increasingly difficult to discern as boundaries between natural and artificial process smear. It will be important to ferret out the ideas that nest within our constructions of nature, not so we can eliminate them, which would be impossible, but so that we can see that our pictures of nature represent a social accomplishment with which diverse, interested audiences can engage. Artificial Life is a project with a capacity for strewing reality with programs and machines modeled after already constituted social categories, programs and machines that might provide yet more "empirical" evidence for the idea that organisms really are automata, really do act selfishly, or really do need stable "sexual" identities to survive. This book is a critical political intervention into the reinvention of nature under way in Artificial Life; it is an argument against the digital naturalization of conventional visions of life and a petition for a greater sense of possibility in the Artificial Life world.

ARRIVING AT ARTIFICIAL LIFE

My path toward doing this study began in the late 1980s when I was in college at the University of California, Los Angeles (UCLA), studying anthropology and dabbling in computer science. Early on, I read Douglas Hofstadter's *Gödel, Escher, Bach* (1979), a book that wove a beautiful tapestry of analogy between mathematics, graphic art, music, computations, genetics, and language. I was enthralled by the possibility that computers and DNA might have something in common, that intelligent machines might be the offspring of human cultural evolution. In my sophomore year, I enrolled in a class in Artificial Intelligence and philosophy with Charles Taylor, a biologist who later became a prominent figure in Artificial Life. I remember how inspired I was by the final lecture in which Taylor argued that living organisms were nothing more than specially organized matter. Life, he said, was just a question of how matter was put together. Inanimate objects had something of life in them simply because they were made of the same stuff as we organisms. As an atheist, I found this idea eerie, and it awoke sensations in me that I could only consider numinous.

As I continued my studies, I fixed my imagination on science fiction–inspired dreams of studying the anthropology of future human evolution; I wanted to know how humans might evolve in outer space, how they might create intelligent computers, and how they might confront their creations as evolutionary rivals. I mined my boyhood fascination with *Star Trek, 2001*, and *Close Encounters* for inspiration. I was committed to a strongly scientific view of the world, manufactured in part by interactions with my mother's father, a chemist and amateur astronomer whom I greatly admired.

My view of science changed when I began work as a biological anthropology tutor for UCLA's Affirmative Action Program. As a white person working with predominantly African-American and Latina/o students, I found myself in uncomfortable and odd positions as I tried to explain the instructor's interest in retrieving a scientific definition of race, when such endeavors had clearly been the cause of so much oppression. My students challenged me to think critically about my racially marked position as a messenger of a version of evolutionary biology—sociobiology—that offered genetic rationalizations for a system of social inequality in which people like myself were among the privileged. I had long felt myself to be anti-racist—since early experiences in integrated elementary schools—and hoped that science would be a tool I could use to bolster my belief in the irrationality of racism. I had not imagined that racism still inhabited the body of contemporary science. I was keenly aware of how scientific racism had been deployed in the past, since my German father had communicated to me the pain of knowing that his parents' generation had joined in the Nazis' ferocious project of racial extermination. My involvement with affirmative action also pushed me up against the politics of race in the university generally, especially as the Reagan-Bush administrations made ever-deeper attacks on civil rights, attacks that my co-workers and I felt as the university targeted our jobs for elimination. I applied to graduate school in anthropology with the idea of learning more about the social shaping of science.

I found out about Artificial Life when I arrived at Stanford University and took a course with the computer scientist Terry Winograd about the failure of Artificial Intelligence to produce truly intelligent machines. I came upon the proceedings of the first Artificial Life conference as I searched for fresh work on "nonrepresentational Artificial Intelligence" and was chagrined to discover sociobiologically inspired speculations about how to make computers into selfish, competitive, and xenophobic creatures. Soon after, I began work as a teaching assistant for courses in human evolution, an activity that amplified my concerns with science and race and that pressed me to reexamine my rather orthodox views on the relationship between biology, sex, gender, and sexuality. Though this tale glosses over uneven personal and professional transitions, it does mark out the steps I took toward studying Artificial Life. How I gained access to Artificial Life scientists is the next piece of the puzzle.

In 1991, I submitted a paper to the first European Conference on Artificial Life. The piece discussed how John von Neumann's theory of self-reproducing automata reoutfitted biblical stories of creation in cybernetic clothing (see Helmreich 1992). When the paper was accepted onto a panel on epistemological issues in Artificial Life, I traveled to Paris to deliver a corresponding talk. Afterward, I was approached by Steen Rasmussen, a physicist working on computer simulation in Santa Fe and Los Alamos. Rasmussen had studied philosophy in his native Denmark and had recently relocated to the United States to pursue interests in Artificial Life. Citing the German social theorist Jürgen Habermas, who has written about the role of communication in constituting a democratic public sphere, Rasmussen said he felt that a cultural and historical understanding was very important to facilitating informed public dialogue about Artificial Life. A series of emails between Rasmussen and me followed, and I obtained permission to do fieldwork at the Santa Fe Institute and to use the Institute as a point of departure into the networked community of Artificial Life. Over the summer of 1992, solidly from May 1993 to July 1994, and again in June 1995, May 1996, and June 1997, I conducted interviews, did archival research, attended lectures and conferences, learned a few simulation platforms in depth, and visited international research sites.[5] I was sustained primarily by Stanford, by a grant from the National Science Foundation, and by the hospitality and staff support of the Santa Fe Institute. The imagery of travel speaks to the privilege with which I was able to move among researchers; I was not an exile, a refugee, or a migrant. I was assimilated into the Artificial Life community with minimal difficulty.

The historian of science Donna Haraway has commented that we should not undertake studies of activities in which we are not implicated, in which we do not have a stake. Though I am not a practicing Artificial Life scientist, I share an investment in examining the assumptions of contemporary biology and computer science. In a world in which computers organize much of everyday life and in which informatic theories of biology guide understandings of human nature and culture, I care about how knowledge about the organic and the digital is produced. I continue to find this knowledge compelling and disturbing, persuasive and problematic, and full of pleasure and danger. I read the following statement of Langton's as an invitation to do my study:

> The *practice* of science involves more than science. Although scientists often work within a world of abstraction and mathematics, the results of their abstract mathematical musings often have very tangible effects on the real world. The mastery of any new technology changes the world, and the mastery of a fundamental technology like the technology of life will necessarily change the world fundamentally. Because of the potentially enormous

> impact that it will have on the future of humanity, on Earth and beyond, it is extremely important that we involve the entire human community in the pursuit of Artificial Life. (1992:20)

Langton's remarks, while ambitious in their vision of the influence of Artificial Life, open a door to considering the science from a cultural perspective. This is perhaps not so surprising, since Langton's undergraduate training was in anthropology, a fact that fundamentally informed my conversations with him and that shaped his generally sympathetic attitude toward my project. Of course, as I will be arguing throughout this book, I do not think a cultural analysis of Artificial Life can be restricted to the impacts of the field, as Langton seems to suggest. Artificial Life is already informed by culture, history, and politics, even unto the most "abstract mathematical musings" that animate it. Recent literature in the social and cultural study of science has brought such recognitions into sharper relief, and I am inspired by this work here, a brief account of which is in order.

SCIENCE AS CULTURE

Culturally dominant pictures of science portray it as a social practice dedicated to producing objective knowledge about the world. This image has a variety of institutional and epistemological supports, not least of which is a scientific education that instills scientists with a sense that they are committed to truth and pursue it in a community organized around professional skepticism. This is a picture that sociologists of science have been busy disturbing for the past twenty years or so. Following philosophers of science such as Thomas Kuhn (1962), who argued that scientists' knowledge of the world is organized by paradigms—that is, culturally agreed upon ways of looking at nature—rather than by unproblematic access to nature, sociologists of science have examined how scientists craft and contest knowledge in social context. On their view, nature does not exclusively direct the production of scientific knowledge; theories are never completely determined by data, and decisions about what counts as nature are often quite social, even political.

Recent literature in the sociology of scientific practice has focused on the laboratory customs of experimental scientists, seeing the production of scientific knowledge as a contingent and agonistic contest between social actors to marshal institutional and rhetorical support for truth claims (see particularly Knorr-Cetina 1981; Latour and Woolgar 1986;

Latour 1987). Such a view, however, has often left the social meaning of scientific knowledge itself unexamined and has neglected to discuss how scientists participate in a system of values, beliefs, and practices that extends beyond the walls of the lab. It has often made no difference to the authors of these works whether knowledge is being manufactured about a protein, a pulsar, or a primate, or whether this knowledge is produced in the service of government regulation, product development, or lay activism. New work in the anthropology and cultural study of science has begun to pry at the cultural meaning of scientific knowledge and has examined scientists as people located in a multiplicity of positions (see, e.g., Traweek 1988; Haraway 1989; Martin 1994; Gray 1995; Edwards 1996; Fujimura 1996; Gusterson 1996; Nader 1996; Rabinow 1996; Galison 1997; Downey and Dumit 1997). Much of this work has built on feminist and anti-racist critiques of science (see, e.g., Bleier 1984; Keller 1985; Harding 1986, 1991, 1993; Haraway 1991a, 1991b, 1991c, 1991d, 1991e; Boston Women's Health Book Collective 1992; Noble 1993). These critiques, historically linked to radical science movements of the 1930s and 1970s, have been grounded in political activism concerning issues such as women's health and the contestation of racist theories of intelligence.

The anthropology of science has begun to dismantle the notion that science is carried out in a world scissored off from the culture in which it exists. Haraway provides a programmatic summary of the view that science is culture in her monumental history of twentieth-century primatology, *Primate Visions:* "My argument is not that 'outside' influences have continued to determine primatology into the period of problem-oriented, quantitative studies, but that the boundary itself gives a misleading map of the field, leading to political commitments and beliefs about the sciences that I wish to contest" (1989:125). I would like to say the same of this study of Artificial Life, and assert that it is no surprise that scientists use "extrascientific" resources in putting together models. The use of resources "outside" science is not a scandal but is science as usual; that we have been encouraged to deny this is the scandal, and is precisely the way an educated public has been prevented from participating in building scientific views of the world. As the sociologist Pierre Bourdieu writes, "The idea of a neutral science is a fiction, an interested fiction which enables its authors to present a version of the dominant representation of the social world, neutralized and euphemized into a particularly misrecognizable and symbolically, therefore, particularly effective form" (1975:36). As members of a powerful institution that derives much of its authority from claiming to transcend human culture, scientists have attempted to enforce through their practice and language the notion that science stands apart from human affairs. Science has become a sacred domain.

This is not to say that there is not something distinctive about scientific practices, about modes of thinking and acting made available in the physical and life sciences. These affect domains apart from science—economics, politics, religion—as much as the reverse. A relativist position, one that holds that all knowledges are equal, ignores the ways science produces powerfully persuasive accounts of what is real, about the world we share and shape. By being forgetful about the conditions of power that mold knowledge, relativism is as bad as objectivism, the position that knowledge can exist without knowers. A view that sees science as social accepts that science has been crafted as a particular way of knowing even as it is crosscut by cultural practices and commitments. Understanding science as culture opens up space for reimagining and intervening in its projects. As the anthropologist David Hess (1992) argues, science is always embedded in a contestable symbolic order and set of power relations and is therefore subject to cultural critique, the object of which is to show that taken-for-granted practices are often quite contingent and could be other than they are (Marcus and Fischer 1986). On this view, Artificial Life does not extrapolate eternal rules of nature into a machine realm but transcribes culturally particular tales into its new creations.[6]

MATERIALIZING NATURE, LIFE, AND CYBORGS

In spite of its novelty as an ethnographic object, Artificial Life is interesting for quite traditional anthropological reasons. The field promises both to reinforce and to disturb the stability of "nature" and "culture," categories that have long been central for organizing Western folk and scientific thought. Nature has meant for many of us that which is moral, inevitable, given, perhaps rationally or harmoniously designed.[7] In many cases it has not mattered whether we appeal to a nature made by God or to nature as it is revealed by science; it has been a reference point for understanding some things as immutable (see Yanagisako and Delaney 1995).[8] As such, it has frequently served as a resource for legitimating social orders—for naturalizing power. As long as nature occupies this politically potent place, it will be critical to examine the cultural tales imported into it.

But Artificial Life may well participate in changing some dominant meanings of nature. "Artificial Life" is, of course, a deliberate oxymoron, meant to shake us into considering the possibility that "life" might not be an exclusively "natural" object or process. If, as the sociologist Karin Knorr-Cetina (1981, 1983) holds, the nature that scientists work with in labs is already highly artificial, and can be seen as the outcome of histories of local, practical decisions about what works (rather than about what is true), then Artificial Life, with its reliance on constructed computer simulation, might make it clear that the only kind of nature we can have is a kind generated through what Haraway has called a "relentless artifactualism" (1991e:295). The anthropologist Paul Rabinow has asserted that in the culture of late modernity "nature will be known and remade through technique and will finally become artificial" (1992:241–242). Practices like Artificial Life may radically reconfigure what we think of as life, drawing attention to the fact that our understandings are constructions in the most literal sense, that they are built from our imaginative and technological resources (see also Emmeche 1991, 1992, 1994; Doyle 1997b).

In her work on the anthropology of new reproductive technologies, Strathern (1992b) examines the shifting relationship between the natural and the artificial in late-twentieth-century Western life. She observes that Europeans and Americans seem increasingly interested in making explicit what they mean by "nature." This happens when they intervene technologically to help "infertile couples" have their "own" "natural" children, when they participate in the conservation of rain forests, when they engage in genetic engineering to change properties of plants and animals, when they produce and consume "natural" foods, or when they program organic dynamics into computers. As they seek to define the natural, they redraw what counts as natural and cultural, solidifying these as categories of thought, but also making nature available for analysis as a culturally constructed item. The distinction between first and second nature erodes.

The idea that nature is what we make it is called "social constructionism." Social constructionism has been a politically powerful tool for contesting naturalizations of inequality. People interested in dismantling structures of domination organized according to categories of gender, race, and sexuality and through economic patterns like capitalism have been eager to show that these categories and patterns are not natural, not biologically given, but are the result of historical and cultural processes. In recent decades, sociobiology has been just one prominent focus of social constructionist debunking. While such critical deconstruction has been useful, it has begged the question of what nature remains when the work of social construction is done. Social constructionism has reproduced as residue the very nature it has sought to dethrone.[9]

Paradoxically, a social constructionist attitude fundamentally enables the science of Artificial Life. Researchers are explicitly concerned with creating new biologies *in silico*, an enterprise that forces them to question whether nature is reflected or constructed in their work. While I find such questioning epistemologically promising, I would like to offer an alternative to social construction, one I borrow from the rhetorician Judith Butler, who proposes that we think of the reality of categories like "sex," "race," and "nature" not as constructed but as *materialized* (1993:9). This means that the realness of things congeals from material practices of meaning making that stabilize "over time to produce the effect of boundary, fixity, and surface" (1993:9). An object or process like "life" does not exist "out there," waiting for us to name it. Neither is it solely the product of active "construction." What "life" is or becomes is "materialized"—comes to matter (in the sense of both becoming important and becoming embodied)—in such practices as describing and fabricating machines and organisms with common metaphors and taxonomies, negotiating boundaries and connections with nonhumans, representing living beings as ordered by their visible structure rather than their smell or taste, and so on. To borrow an argument from Haraway about nature, the fact that "life" exists for us at all "designates a kind of relationship, an achievement among many actors, not all of them human, not all of them organic, not all of them technological" (1991e:297). This book, though centered on the human agencies enlisted in the making of Artificial Life, tries to get at how new notions of life are being materialized, specifically, at how life is being crafted to inhabit both the natural and the artificial—a process that is already transforming our meanings of nature, evolution, and life. This mutation bears watching because, as Haraway notes, "if technoscience is, among other things, a practice of materializing refigurations of what counts as nature, a practice of turning tropes into worlds, then how we figure technoscience makes an immense difference" (1994:60).

The object that Artificial Life researchers are seeking frenetically to mime, to reproduce, namely "life," has been notoriously difficult to define. And as researchers forward new candidates for vitality, they both stabilize and undermine any definitional enterprise. The historian Michel Foucault reminds us that the category "life" is in fact a relatively recent invention:

> 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.* (1966:127–128)

Only with the rise of Darwinian notions of evolution and accompanying ideas about the underlying relatedness of all living things did it become possible to conceive of life as something in itself. "Life" emerged at the end of the nineteenth century as an invisible unity, a force or principle unifying the visible forms of living things.[10] "Life" became an elusive quality, a "secret" to be sought in the threads that tied living things together, an essence to be located in the filaments that maintained relationships between living beings. In the twentieth century, scientists came to see "life" as residing in the substance of DNA, in a "code" that could be read. This definition of life has materialized new life-forms, such as genetically engineered animals and plants, as well as new ways of thinking the human, as a cybernetic organism endowed with a genetic potentional and profile. The extension of the genetic code metaphor to grant computer programs vitality promises unexpected new materializations of "life." Locating changing concepts of animation in cultural context matters because understanding and managing "life" has become an important political activity; one has only to think of the place of "life" in debates about environmentalism, abortion, euthanasia, and new reproductive technologies (and see Taylor, Halfon, and Edwards 1997). As a trend-setting science, Artificial Life may provide a window into the changing scientific definitions of life that crisscross these controversies.

Foucault argued that discourses that fence in life first became potent political items in the nineteenth century. He designated "bio-power" as that which "brought life and its mechanisms into the realm of explicit calculations and made knowledge-power an agent of transformation of human life" (1976:143). Control over definitions of life has made our bodily practices the subject of disciplining technologies and knowledges. Bio-power operates less through controlling people than by defining them, by constituting their identities such that they believe they fit into already extant natural categories. Bio-power populates reality with subjects constituted according to its definitions, thereby providing empirical evidence that the categories are real. It operates through religious, scientific, medical, educational, and state institutions, as well as through the politics of everyday life—in the bedroom, the kitchen, the office. It circumscribes the space of the acceptable, gives rise to new modes of subjectivity. If men and boys feel guilty for masturbating because they believe in some way that they are dissipating their "life-force" unproductively, this is an operation of bio-power. If women's menstruation is constructed as disqualifying them from "normal" political life (modeled after a male norm), then bio-power is at work here, too. As the organic and the technological merge, mix, melt, and mutate, however, we might be better served to look through the lens of the "cyborg," the human-machine hybrid first theorized in the mid-twentieth century in the service of the U. S. space program's mission to integrate humans with extraterrestrial life-support systems (Clynes and Kline 1960). Haraway may be right that "Michel Foucault's biopolitics is a flaccid premonition of cyborg politics" (1991d:150).

Seeing the cyborg as a prosthesis for cultural theorizing comes famously from Haraway (1991d), who proposed the cybernetic organism as a figure for a new politics of connection, affinity, and boundary transgression. As a feminist coming of age in the 1960s and 1970s, Haraway was wary of identifications of "women" with "nature" and desired attention to the way identities were socially built. Identifying women with nature may have been empowering for some, but it invited patriarchal appropriation; if women were closer to nature than men, they were leashed to whatever dominant biological science decided their natures were. The cyborg, continually changing in response to new feedback, not entirely natural or artificial, could be a more elusive and empowering figure, never stable, never fixed by original difference. In a sense, Haraway argued, we are already cyborgs: our bodies and identities are amalgams of the natural-technical codes of DNA, human language and its metaphors, the history of sexism, racism, and colonialism, and the ergonomic logics of early and advanced capitalism. Haraway argued that rather than bemoan this state of affairs, we would do well to appropriate it for liberatory ends.

Cyborg politics can force us to examine and take responsibility for the ways human enterprise and the organic world are ever more implicated in one another. Recent years have seen the growth of "cyborg anthropology," a practice that seeks to examine "ethnographically the boundaries between humans and machines and our visions of the differences that constitute these boundaries" (Downey, Dumit, and Williams 1995:342). Cyborg anthropology acts amid the contradictions of technoscience, looking for liberating and oppressive stories commingling in the science we produce. My account of Artificial Life joins in this project of mapping the disturbed social and political boundaries between human and machine.

ETHNOGRAPHY, POWER, AND WRITING

With few exceptions, the subjects of traditional anthropology have been people in positions of less power relative to the anthropologist, who has been privileged to travel, to take time to immerse herself or himself in "another culture," and to produce a text that her or his subjects may never read. Doing anthropology among powerful people is different. Many do not like to be studied and can easily prevent anthropological access to their lives, although "this power can also produce what an anthropologist who has studied . . . elite institutions has called 'the confidence of class'— a sense that one's position in the culture is assured and unassailable" (Lutz and Collins 1993:48). The powerful have means to protect their interests and to contest their portrayal by journalists and social scientists. I must be aware that my writing exists in the same academic and cultural contexts as the people I write about.

In anthropology, the activity of studying powerful people is called "studying up" (Nader 1974).[11] The reasons for studying up are myriad, and include investigating the sources of one's political indignation at the practices of power, a curiosity to see how influential knowledges are produced, and an impulse to make the customs of the powerful available for public scrutiny. The consequences of studying up can be diverse; one may lose funding, get sued, gain unexpected allies, or be conscripted into a new way of life. The dynamics are not necessarily quite that simple, either. Within communities there are differentials of power: the power I had with respect to people in the Artificial Life community varied, as I entered into alliances, disagreements, and confrontations with people differently positioned in the field. My participation in the community meant having opinions, making friends and foes, and caring about its theory and practice. This book cannot be a definitive account of the social world of Artificial Life. It is a partial story, informed by my own history, training, and interests—as any story told by a located human being, in any kind of circumstance, must be. Nevertheless, I believe I have captured important cultural dimensions of Artificial Life work. I hope that Artificial Life workers recognize something new of themselves in my account.

There is something peculiar about the academic and institutional configurations that have allowed anthropologists to walk into high-tech laboratories, something that makes scientists laugh when I tell them what I do. I think this laughter bespeaks an uneasy recognition of the coercive and colonial relations that produced anthropology historically as the study of nonmodern "others," but it also reveals an increasing sense—even among those most disposed to believe in objectivity—that everybody's closest beliefs may seem strange when viewed from another angle. An anthropological common sense has infiltrated Artificial Life researchers' view of themselves to such an extent that many deploy a gentle irony when asked to reflect on their practices and beliefs. They know that they appear to others as singular characters.

Which brings me to how they appear as characters here. It is conventional in ethnographies to give people pseudonyms or to otherwise protect identities. People often speak in confidence, and such devices of disguise can protect them from being identified by those who might use their words against them. Sometimes people need to be guarded from uninvited questioning by other community members or from emotional, financial, and physical embarrassment or threat. Nothing I report will put anyone in great jeopardy, but I am still careful with the words I gathered. I have checked transcripts with every person I interviewed and asked them about the preferred disposition of their words. Some people appear with their real names attached to interview data while others are given pseudonyms. Sometimes people named in one passage appear under pseudonyms (or even anonymously) in another. Real names include surnames; pseudonyms do not. Through much of this book I rely on researchers' published papers and public talks, and for these I always give proper attribution.

A SEQUENCE MAP

This book is structured by images of travel through worlds real and virtual. Chapter 1 surveys the geography of Santa Fe and the Santa Fe Institute, exploring the history of these spaces and the people associated with them. Chapter 2 moves into the worlds that materialize within computer simulations. Chapter 3 is an extended tour of several simulation systems, notably Tom Ray's Tierra and John Holland's Echo. Chapter 4 follows the narratives of Artificial Life out of the computer and into the lives of researchers, asking how practitioners use their work to reflect on questions of personal and cosmological meaning. Chapter 5 reaches into the worldwide web of Artificial Life, paying particular attention to European networks and investigating how diverse definitions of "life" circulate in an increasingly diverse transnational community. The coda closes with a report on Artificial Life in Japan and with meditations on the future of the field.

Because Artificial Life metamorphoses so rapidly, I cannot hope to provide an up-to-the-minute report on the latest turns. As I write this introduction, many of the ideas I discuss here are beginning to sediment into a general common sense, in science and elsewhere. Simulation technology has become less extraordinary, as has the notion that living beings are information-processing systems. Thus this ethnography can be read as an account of how some of us came to think and act the way we do. It is not surprising that Artificial Life has settled into a comfortable past. In its very conception, Artificial Life imagines that it is always in danger of being outmoded, superseded by the products of its own practice. This book races alongside that imagination, with a view toward understanding the shape of things to come in an age of silicon second nature.