THE SMARTNESS MANDATE

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ORIT HALPERN AND ROBERT MITCHELL

THE MIT PRESS CAMBRIDGE, MASSACHUSETTS LONDON, ENGLAND

The MIT Press would like to thank the anonymous peer reviewers who provided comments on drafts of this book. The generous work of academic experts is essential for establishing the authority and quality of our publications. We acknowledge with gratitude the contributions of these otherwise uncredited readers.

This book was set in Stone Serif by Westchester Publishing Services, Danbury, CT. Printed and bound in the United States of America.

Library of Congress Cataloging-in-Publication Data is available.

ISBN:

10 9 8 7 6 5 4 3 2 1

CONTENTS

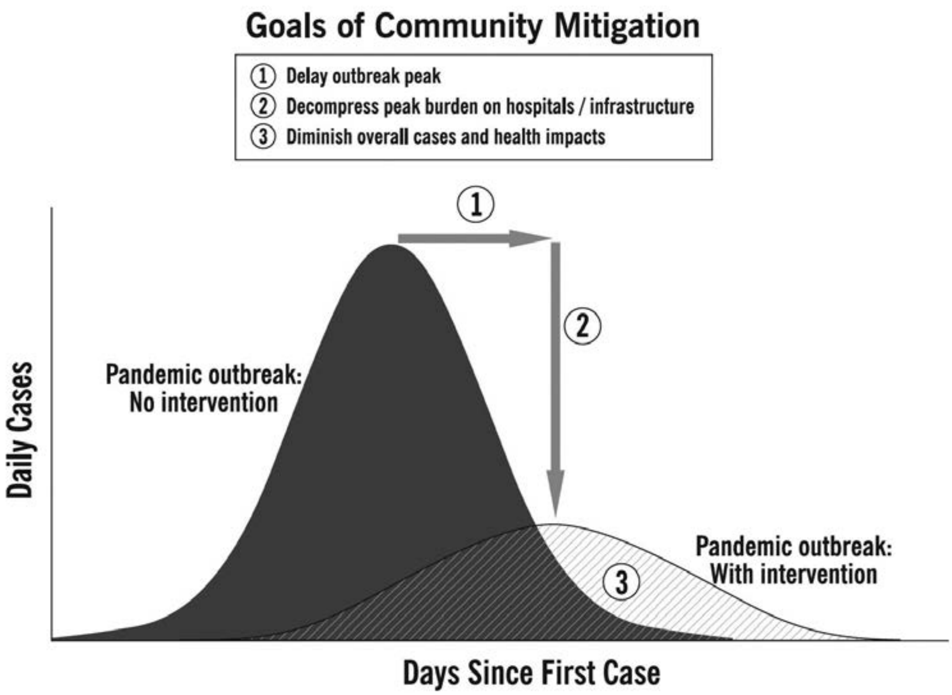
4

RESILIENCE

In the midst of the COVID-19 pandemic, invocations of both a present and future "new normal" circulate ad nauseam throughout news outlets and social networks. This new normal has multiple, and often contested, dimensions, denoting the likelihood that social distancing protocols will remain in place for many years to come; that app-based health monitoring and access will become even more central to daily life; and that increasing precarity for many and a dramatic increase in profits for a small few will continue unabated, to name just a few proposed aspects of the new normal. Ubiquitous curve graphs and data visualizations help us to grasp these dimensions of the new normal.

This language invokes not only a now vanished "old" normal, which becomes an object of nostalgia, but also encourages us to reconsider the concept of the normal itself. As Georges Canguilhem, Michel Foucault, and François Ewald, among others, have noted, the concepts of norms, normativity, and normalization came to prominence in the eighteenth and nineteenth centuries and were bound up with, and to, concepts of economy, population, and race. Invocations of the normal in these discourses were also necessarily claims about nature, even if, as Foucault stressed (following Canguilhem), the nature referenced by practices of what he called "normativity"—that is, the use of the human sciences to locate new possible norms and "nudge" social relations toward those—was understood as pliable and capable of change. Though we may now believe that nature and culture cannot be rigorously distinguished and that we live in a modulatory, postnormal, postanthropocentric, and posthuman society, the invocation of the new normal emphasizes the continuing importance of this ideal of a nature that would enable both the old and the new normal.

But if the language of the new normal contains an implicit reference to nature, what form of nature is this, precisely? We can begin to approach this question by considering calls for cities or states to "flatten the curve" (see figure 4.1). The goal and language of infection curve flattening emerged from a 2007 US Centers for Disease Control and Prevention article on the community-based mitigation of pandemic influenzas.[1] This discourse has



4.1 Chart illustrating CDC plans for managing a pandemic, published more than a decade before the start of the COVID-19 pandemic. *Source*: Centers for Disease Control and Prevention, *Interim Pre-pandemic Planning Guidance: Community Strategy for Pandemic Influenza Mitigation in the United States—Early, Targeted, Layered Use of Nonpharmaceutical Interventions* (Atlanta: Centers for Disease Control and Prevention, 2007), 18.

some curious features. The assumption that we *will* end up on the curve and that the best we can do is to flatten it assumes that pandemics are inevitable, although it is uncertain when and where they will start. Such a premise was prepared both by public health officials' warnings about coming pandemics, by the emergence of infectious diseases such as HIV/AIDS in the Global North, and by popular nonfiction books and movies with titles such as *The Hot Zone*, *The Coming Plague*, *Outbreak*, and *Contagion* (not to mention the slew of zombie-apocalypse films and television shows that fill our imaginaries with the logic of infection). Virtually no one in public health doubted the possibility of another zoonotically transferred pandemic; the only question was when. This means, in turn, that though pandemics are clouded in uncertainty—*Which* disease will it be? *When* will it hit? *From where* will it emerge, and *to where* will it spread?—they are still understood as events that will inevitably need to be managed. Pandemics are, in short, "known unknowns."

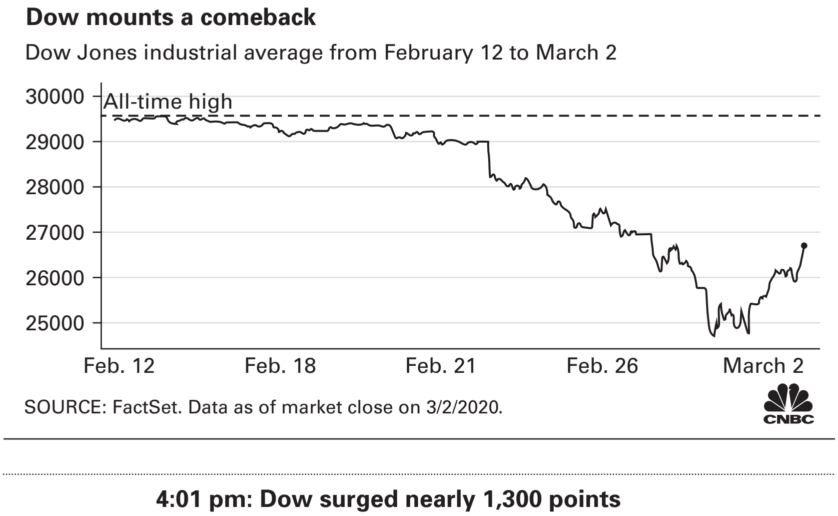
The discourse of curve flattening also assumes that efforts to mitigate the consequences of new infectious diseases will always be significantly hampered by human-created obstacles that seem in principle preventable. Public health professionals and many others fully understand that better urban planning, more social equity, stronger public health infrastructures, transformed agricultural systems, and improved environmental management would likely prevent many future pandemics. Yet few actually believe that these infrastructural changes will occur, no matter how many lives such measures would save. As a consequence, the best we can do is to manage this uncertain event (i.e., flatten the curve). Because COVID-19 spreads through the act of breathing, we have to slow the metabolism of the social system so that we can accelerate the demise of the virus. This is an example of the management of temporalities: a strategy that assumes catastrophe *will* occur but that there are ways to address this trauma. Those ways, as mentioned in chapter 2, largely involve an army of tracking apps, the construction of ever more digital surveillance, and, of course, new modes of working, learning, and living online.

Our primary goal in this chapter is to trace the genealogy of (1) the premise that environmentally induced trauma should not be understood as either an event or shock, but simply itself the new normal, and (2) that, as a consequence, humans must develop "resilient," data-intensive structures that can transform what earlier would have been considered a catastrophe into a managerial possibility. Our approach borrows from the work of Lisa Parks and Janet Walker, who discuss *disaster media*. For them, disaster media is a heuristic that allows us to understand how environmental and "natural" catastrophes are coproduced with media infrastructures, which in turn creates new forms of governmentality, narrative, and inequity.[2] We trace here the emergence of the contemporary concept and practices of resilience, with resilience understood as that which enables management in the face of constant change and crisis; demands large-scale and distributed information gathering; emphasizes speculative scenario planning (which itself requires financial speculation); and, as a result, conceptualizes the planet and life itself as test beds for demo-ing possible futures.

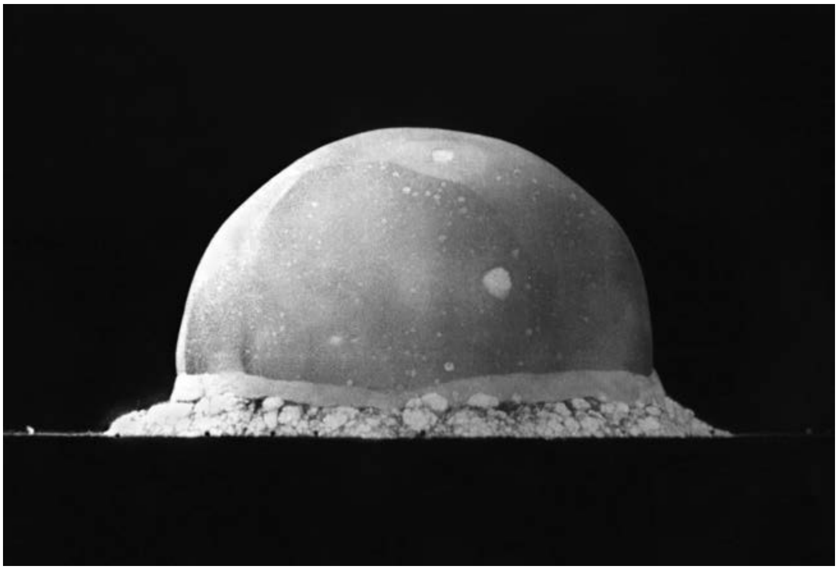
Our account has three parts. In the first we document how the development of ecosystem ecology between the 1940s and 1960s helped to reconfigure approaches to the environment in ways that would subsequently make it graspable as a medium for computation and speculation. Ecosystem ecology itself, though, did not take this step, and in the second section we focus on the emergence of the notion of ecological resilience in the 1970s, stressing that this concept explicitly critiqued the concept of homeostasis central to ecosystem ecology, and implicitly challenged the idea of "limits" promulgated in the report *The Limits to Growth*. In the third section, we use the example of *adaptive management* techniques to trace the merging of ecological concepts of resilience with business practices, with the treatment of ecologies as "service providers" acting as a key link between these discourses. Recalling our examples from chapter 2, our conclusion to this chapter notes that smartness is often oriented toward the goal of making urban spaces and other infrastructures "resilient" to climate change in a manner that makes some populations vulnerable and expendable while maintaining the wealth and power of others (a dynamic exemplified in figure 4.2). This chapter not only aims to understand how this itself became the new normal but also seeks to point out alternatives to this vision.

FROM SYSTEMS ECOLOGY TO ALLOPLASTICITY

On July 16, 1945, in the New Mexico desert, the first nuclear device was detonated (figure 4.3). The result of one of the most massive scientific



4.2 Dow rally on Monday, March 2, 2020. *Source*: CNBC, "Dow Rallies Nearly 1,300," accessed June 2, 2020, https://www.cnbc.com/2020/03/02/stock-market-today-live.html.



4.3 Trinity test fireball at 16 milliseconds after detonation, Alamogordo Bombing and Gunnery Range, New Mexico, July 16, 1945. *Source*: Wikipedia, s.v. "Trinity," last modified February 6, 2022, https://de.wikipedia.org/wiki/Trinity-Test#/media/File:Trinity_Test_Fireball_16ms.jpg.

efforts on earth, the Trinity test would enable the design of the bomb named Fat Man, which was dropped on Nagasaki, Japan, three weeks later. The test, in other words, almost immediately ceased to be a test and became a reality.

After witnessing the Trinity test explosion, J. Robert Oppenheimer, the scientific director of the Manhattan Project, quoted the Bhagavad Gita: "If the radiance of a thousand suns were to burst into the sky, that would be like the splendor of the Mighty One." As the large mushroom cloud bloomed over the desert, another line from the same scripture came to his lips: "I am become Death, the destroyer of worlds." Oppenheimer would soon turn publicly against his own invention, unable to stomach the fact that he had helped to construct a technology that would shatter the world—that is, a machine designed for nothing but death and that, simply through its testing, had already transformed all life on earth.[3]

The Trinity test marked a pivotal moment when species survival and technology were intimately, and horrifically, intertwined. Radioactive fallout from the test ensured that every element of life was penetrated by the effects of human technology, which is also to say design. The very shell of the planet was transformed geologically by radiation. Today, the radioactive trace of this test is one of the main markers used by the geological sciences to demarcate the newly proposed geological era of the Anthropocene. This test defined the moment when human materials and technologies entered the earth's crust and could be scientifically measured. It also heralded the start of a new technical era that has reshaped the planet's climate and geology. And by helping to end World War II with a US/Allied victory, the Trinity test inaugurated the rise of American empire and the start of the Great Acceleration and the Information Age. All of these developments were driven by the new energy and computational machines unlocked through the war. In this sense the Trinity test marked the moment when technologies and life could no longer be separated and when design could be understood as techne for transforming human life at a planetary scale—sometimes through computation and calculation; sometimes by using populations, both human and animal, as media; and even more often by linking computation and populations.

Oppenheimer's reflections on the outcome of what remains to date one of the largest and most technically intensive and expensive design projects in human history would be uncannily repeated by the designer Victor Papanek some 30 years later to describe a new feature defining the human. Humans, Papanek argued, cannot be distinguished from nonhuman animals by their possession of either language or toolmaking. The nascent and interrelated sciences of ecology, sociobiology, cybernetics, and ethology had discovered, for example, that bees have languages, and other animals construct vast architectures. Rather, Papanek argued that

> mankind is unique among animals in its relationship to the environment. All other animals adapt *autoplastically* to a changing environment (by growing thicker hair . . . etc.). . . . Only mankind transforms earth itself to suit its needs and wants *alloplastically*. This job of form-giving and reshaping has become the designer's responsibility.[4]

Humans, Papanek argued, make climates rather than adapt to environments. Humans can indeed destroy worlds, as Oppenheimer noted, but for Papanek, this possibility was grounded in the more fundamental human capacity to *make* worlds.

Papanek's claims were part of a more general rethinking of the concept of the environment in the 1960s and 1970s. Where environment had earlier tended to be understood as either a set of forces external to the body or as the habitat within which living beings found themselves, Papanek conceptualized environment as a medium akin to other media, such as film, photography, or metal, that could be given form and reshaped. Papanek was among the first to conceptualize what we will call the *planetary test bed*. We adapt this term from Papanek's colleague and inspiration, the architect Richard Neutra, who referred to the "planetary test," though we modify the phrase to underscore the technical and engineering aspirations of this approach.[5] Within this vision, the planet and all its populations—of humans, information, materials, and nonhuman lives—are reenvisioned as a milieu for the growth of computation. This also means rethinking human life and habitat as an experiment and opportunity for design intervention and growth at a planetary scale. Design, Papanek implied, should no longer focus on adaptation to an environment understood to be outside human control but rather should be understood in terms of a more fundamental capacity for alloplasticity—namely, the forming and reshaping of the earth. It is our gift, or curse, to deny adaptation and instead desire technical and design interventions.

Our goal in this section is to document the steps—primarily, though not exclusively, in ecosystem ecology—that led from Oppenheimer's horror at the irreversible effects of the Trinity test on the planet itself to Papanek's enthusiasm about the possibilities this enabled for rethinking our planetary condition. Our first stop on this path is a key linkage established in the late 1940s among nuclear testing, risk management, and the study of ecology.

Between 1948 and 1958, the United States used the string of newly acquired Marshall Islands to conduct roughly 50 nuclear weapons tests. These so-called Pacific Proving Grounds ended up being ground zero for both nuclear technology development and for the birth of a cybernetically informed ecology. These tests unleashed massive amounts of radiation into the surrounding environment and seas, affecting the flora, fauna, and people of this territory. With the usual arrogance of empire, Americans treated the irradiated Indigenous people and animals as resources for developing new technologies and knowledge. Dr. Robert Conrad, the doctor in charge of testing and medical care for the hundreds of Marshallese on the islands who had been exposed to radiation, suggested in a 1957 memo that the Islanders could "afford most valuable ecological radiation data on human beings."[6]

As Elizabeth DeLoughrey notes in her brilliant analysis of the Pacific Proving Grounds, this epistemology of power was underpinned by the "myth of the isolate." As DeLoughrey and Richard Grove have documented, both the concepts of Eden and "the deserted island" were critical in enabling the rise of both modern science and colonialism. Since at least Sir Thomas More's *Utopia* (1516), the isolated island was understood as a space located outside of European culture and society that had its own set of rules. In More's *Utopia*, the isolated island was a mirror world for possible political reorganizations of Europe. Through the figures of the Pacific Islands and the New World, islands served as critical imaginary spaces that allowed Europeans to imagine that they were encountering others who either were not human or at least were not as human as themselves. The island could therefore legitimately serve as a laboratory, a place where conditions not normally encountered in the mundane European world could be found or induced.

Perhaps paradoxically, this fantasy of a space from which European social order was absent and in which one could encounter "nature" sat comfortably with projects of terraforming and transforming these supposedly isolated, pure, or primitive habitats into more civilized ones. From the draining of swamps in Palestine to combat malaria, to the transformation of agricultural systems in India, to the dredging of ports and rivers to expand trade, empire, terraforming, and geoengineering have long been accomplices of one another. Terraforming is not a contemporary discovery. The civilizing mission included taming nature and making it economically productive in the terms set up by plantation systems, mineral and energy extractive economies, and, later, industrial agriculture.[7]

Beginning in the late nineteenth century, ecology had a particularly important place within these sciences of empire. "Isolates," whether they were literal islands or geographies that could be treated like isolated islands, were central to the development of ecology: Charles Elton's seminal concept of the food chain, for example, was based on his research on Bear Island, a small arctic island that contained fewer than 100 animal species, while G. Evelyn Hutchison (whom we discuss at more length below) developed many key ecosystem notions through his study of Linsley Pond in New Haven, Connecticut.[8] The premise of the ecological isolate, as historian of ecology Joel B. Hagen notes, was that the ecological processes located in the isolate "were comparable to those operating in the biosphere as a whole."[9]

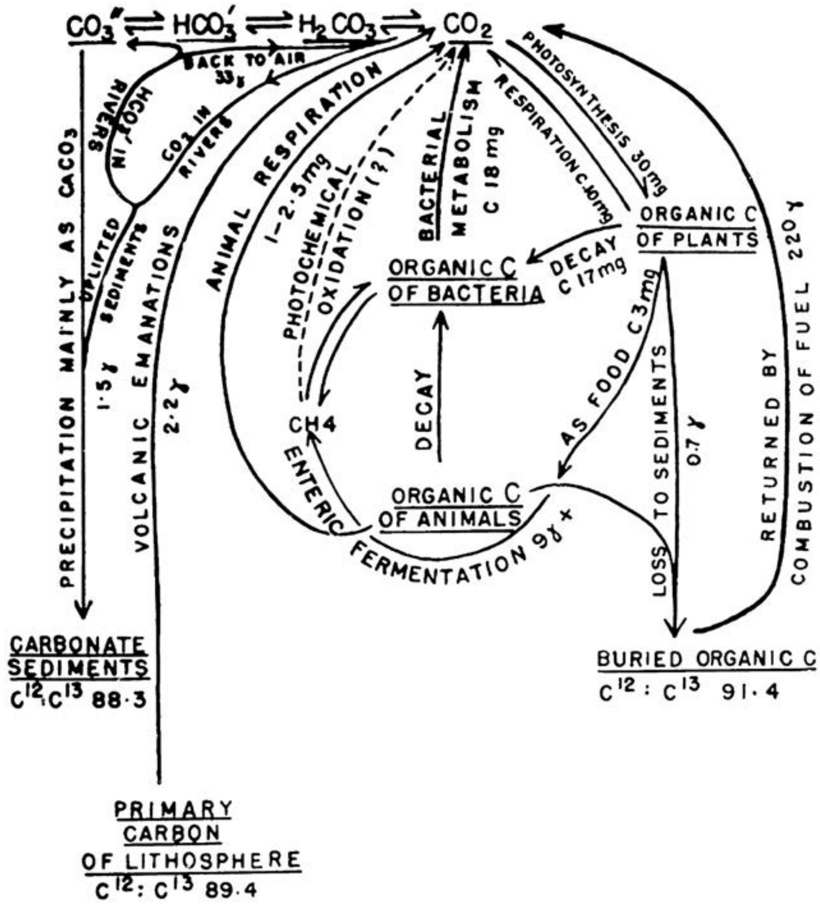
Early twentieth-century ecologists also often adopted a mechanistic approach to nature and these isolates. Historian of science Peder Anker argues that the British naturalist Arthur Tansley, who coined the term "ecosystem" in the 1920s, "believe[d] . . . that a complex system like the human mind or society could be explained in terms of simple biological processes, which in turn are based on physical and chemical laws of energy."[10] Tansley also understood nature as something that could be managed in an industrial and colonial manner. The study of ecosystems became integral to the mechanical maintenance of the machineries of empire. Colonial administrators who took inspiration from the new concepts of ecosystems came to naturalize the order of the British Empire as the reflection of the order of nature. Concepts of evolution, apex ecosystems, and holism, all of which were central to late nineteenth- and early twentieth-century ecology, reinforced the idea of Britain's ascendance; in this sense, models of nature justified models of governance.[11]

In the post–World War II period, nuclear technologies enabled the concepts of the island isolate and the ecosystem to combine in a new way, for exposing a purportedly isolated island to radioactivity enabled the development of a cybernetic imaginary of the ecosystem. More specifically, nuclear tests provided ecologists with a new way to see the relations between living beings by providing scientists with a new form of inscription.

Howard and Eugene Odum, among the most successful ecologists of the era, visited the Marshall Islands from 1954 to 1955 in order to study the Eniwetok Atoll, part of the Pacific Proving Grounds. Howard Odum had focused in his dissertation on the movement of strontium in the environment, while Eugene had investigated the ecosystems around the Savannah River Site in Aiken, South Carolina, where nuclear materials were processed for weapons. The coral reefs of the atoll presented the ecologist brothers with an imagined isolate and extreme laboratory. They understood these reefs as extremely varied ecosystems that, "save for [minor] fluctuations," seem "unchanged year after year, and reefs apparently persist . . . for millions of years." Their primary question, then, was the following: "How are steady state equilibria such as the reef ecosystem self adjusted?" Yet immediately after noting their interest in equilibria, they turned to a massive change: "Since nuclear explosion tests are being conducted in the vicinity of these inherently stable reef communities, a unique opportunity is provided for critical assays of the effects of radiation due to fission products on *whole populations and entire ecological systems in the field*."[12] The bomb produced a new expanse of testing and a new test bed at the scale of the ecosystem, but it also opened the fear of change. Instability and disruption could now happen at speeds not imagined by ecologists, who envisioned systems stable for eons, during which evolution progressed at steady but slow speeds. The Odums' work would pioneer a new form of ecological perception that combined materialities and methods bridging the emerging sciences of communication and control: cybernetics, systems theory, and computation.[13]

For the Odums and the ecologists who followed their lead, radiation inscribed the movements of materials and energy throughout ecologies in ways that enabled these movements to be visualized and quantified. Radiation was soon to be equated with energy and metabolism and hence became a method for visualizing food chains in a system. In making these metabolic relations visible, research at these grounds opened the way to thinking of life at a planetary scale in terms of information or data transfer (understood as quantities of energy) and also made these complex networks both visible and capable of being modeled. In this sense, the ecological work done throughout this period laid the foundations for the subsequent computational modeling and designing of environments.

Howard Odum was particularly important to this process, for he extended significantly the role of concepts and practices of feedback, cybernetics, and simulation into ecosystem study. Odum was a student of Yale ecologist G. Evelyn Hutchinson, who attended the Macy Conferences on Cybernetics in New York in 1946 and was among the first to begin applying systems theories emerging from the new sciences of communication and control to ecology.[14] In his paper for the conference "Circular Causal Systems in Ecology," Hutchinson introduced what he described as biogeochemical and biodemographic approaches to ecology. The biogeochemical approach sought to merge the study of biology with that of geology. Hutchinson suggested that this would be a largely quantitative approach, which would employ flowchart-like diagrams to document the relations of energy and chemistry among different parts of a system (see figure 4.4). The biodemographic approach was more conceptual and did not measure anything, though it was grounded in abstract mathematical models that purported to describe population growth and behavior; these models were intended to reveal the conditions "under which groups of organisms exist . . . [and were] self-correcting within limits."[15] As the historian of science Peter J. Taylor argues, "For Hutchinson whether ecology was biogeochemical or biodemographic—it was nevertheless united by a theoretical proposition: Groups of organisms are systems having feedback loops that ensure self-regulation and persistence."[16] For Hutchinson's cybernetically informed version of ecology, systems were composed of feedback loops that facilitated adaptation, survival, and stability.



4.4 Hutchinson's image of biogeochemical processes. *Source*: G. E. Hutchinson, "Circular Causal Systems in Ecology," *Annals of the New York Academy of Sciences* 40 (1948): 221–246.

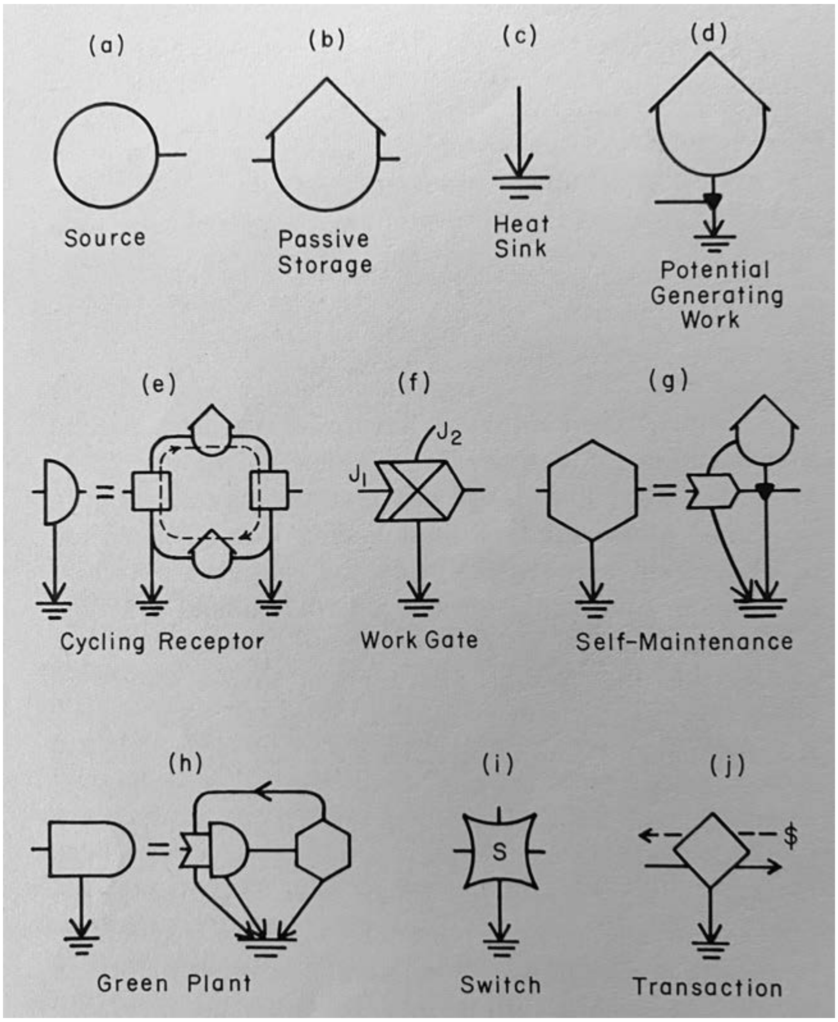
Howard Odum extended these concepts of his mentor throughout his work. His research on the Eniwetok Atoll, for example, established a paradigm of mapping the relations between organisms in ecosystems and producing representations and models of the system. Radiation played a key part in making visible the metabolic cycles—for example, phosphorus, nitrogen, and carbon cycles—and energy consumption of systems. Odum went on to conduct a vast body of research, including a major study in which parts of a tropical forest in Puerto Rico were irradiated in order to examine the impact that radiation and technology have on ecosystems. As Odum argued in 1983, his overarching research goal had been

> to develop a systems language that would combine features of actual systems, drawing from other systems languages as needed. An energy circuit language of symbols and diagrams was developed combining kinetics, energetics, and economics. It does mathematics symbolically but at the same time keeps track of energy laws. In the process of its use it was realized that the diagrams are themselves a form of mathematics with emergent theorems and perceptions for the workings of the mind that extend the capacity to see wholes and parts simultaneously.[17]

Odum was in this sense a pioneer of a new form of technical vision that permitted local measurement to take on planetary or scalar proportions and thus bridge the very small and the very large—or, as he put it, the "wholes and parts simultaneously."[18]

Part of Odum's technical vision was to model parts of the world through generative flowcharts that trafficked in the same language of electrical engineering that underpinned early computing and computer programming (figure 4.5). He imagined and built analog "machines," so to speak, that mapped energy by means of a visualization practice analogous to programming and organizational charts of the time and were visually like circuit boards. Odum took ideas of information and combined them with energy and feedback to begin modeling how systems self-regulated. These diagrams became both simulations of future ecosystem behavior and epistemologies of organization.

The concept of energy was central to Odum's project of approaching ecosystems through the lens of engineering concepts. Borrowing from practices of circuit design in electrical engineering, Odum treated energy as a common unit for representing processes between discrete elements or units within ecosystems. Energy was bound to ideas of feedback in engineering, and representing ecosystems in terms of energy enabled one not only to represent these systems but to do so in a symbolic language commensurate with, and translatable into, digital computation. One cost of this approach, however, was that the separate ecosystem elements that the ecologist identified—for example, a specific animal population—were treated as homogeneous units. In treating ecosystem populations in this



4.5 Energy-circuit "language" for modeling ecosystems. *Source*: H. T. Odum, "The Rain Forest and Man: An Introduction," in *A Tropical Rain Forest*, ed. H. T. Odum and R. F. Pigeon (Oak Ridge, TN: U.S. Atomic Energy Commission, Division of Technical Information, 1970), A-6.

way, Odum explicitly drew on the mathematician and statistician Alfred J. Lotka, who himself had drawn on thermodynamic physics to develop a series of equations in which the members of populations were treated like identical particles of gases.[19] Although this approach allowed Odum to treat the populations of an ecosystem as nodes within a circuit or network, it also moved interest away from those questions of change, novelty, and speciation that, as we noted in chapter 1, were central to the population thinking for which Ernst Mayr advocated.[20]

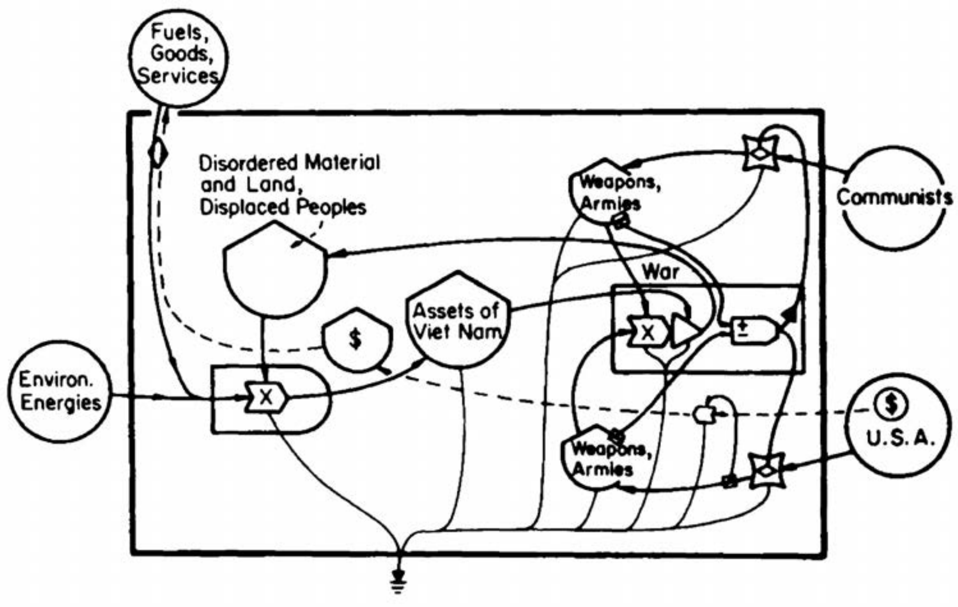
One consequence was that Odum's flowcharts allowed ecologists to envision the world as calculable, computational, and dynamic only because they also presumed that ecosystems naturally tended toward homeostasis. The concept of *apex ecologies*, for example, was a way of acknowledging change but containing it within the frame of homeostasis. One ecology would give way to another, but this would eventually lead to—or at least tend toward—a final stable "apex" ecology. For Odum, the coral reefs of the atoll were such a system, for they could remain "unchanged year after year . . . for millions of years." More generally, we can say that the premise of "isolating" ecosystems for study, and imagining that a system could be modeled and its future managed in its entirety, tended to position *change* as a disturbance, rather than an endemic condition. This did not mean ignoring change: Odum's work on the coral reefs, for example, was made possible by the human introduction of new radioactive isotopes into the environment. But it did mean understanding ecology as the study of the means by which ecosystems resolve change into stability.

This simultaneous interest in change and the valorization of homeostasis and stability was not specific to Odum but rather integral to the cybernetics discourse upon which he drew. For cyberneticians and the many disciples of midcentury operations research and communication sciences, the world *was* fundamentally stochastic, prone to accidents and unforeseen events, and thermodynamic entropy would always prevail in the long run. At the same time, cybernetics presumed that feedback and careful engineering would enable pockets of self-organization and regulation that ran counter to the inevitable degradation to which the second law of thermodynamics pointed. The key, then, was to keep change and disturbances small and continuous, and so within the operating limits of well-engineered systems. The real problem, from this perspective, was volatile and dramatic change and disruption, which was incommensurable with homeostasis. In the realm of political analysis and policy, for example, cybernetics-inspired analysts and policy-makers felt confident that game-theory models could keep in check the "closed" competition between the world's two nuclear superpowers, the US and the USSR. However, they feared that the decentered and networked world that was emerging in the wake of decolonization and economic transformation in the 1960s would not allow for this kind of stability and homeostasis.[21]

THE LIMITS OF LIMITS: FROM THE CLUB OF ROME TO RESILIENCE

Howard Odum's valorization of homeostasis within ecosystem ecology had implications leading in two quite different directions. On the one hand, Odum's understanding of ecosystems as made up of discrete components that could be represented in flowchart fashion and as tending toward stability and homeostasis enabled him to develop a sense of both the connections among, and the vulnerabilities of, the parts of the planetary ecosystem. He was a pioneer in recognizing that energy and its metabolism had implications for both humans and all animal life and in encouraging the belief that this planetary metabolism could be modeled and perhaps even optimized by means of machines. This vision—though often developed by Odum with the help of military funding—provided tools for identifying environmental injustices; the threats that industry posed to various ecosystems; and the costs of human violence, such as war, that resulted from the military-industrial complex (see figure 4.6).[22] Equating social and environmental engineering by means of both the model of the flowchart and concepts of connectivity and communication thus meant an ability to envision *changing* social and natural environments, both for the better and for the worse. In producing a shared language between computation and environment, Odum's innovations paved the way toward making ecology a medium for design.

On the other hand, Odum's cybernetic-derived emphasis on stability and homeostasis meant that intentional changes to the world's social and natural economics could only be understood as virtuous if such changes were oriented toward a stable, "final" state that, like the coral reefs, could persist unchanged. The possibility of *constant* change was,



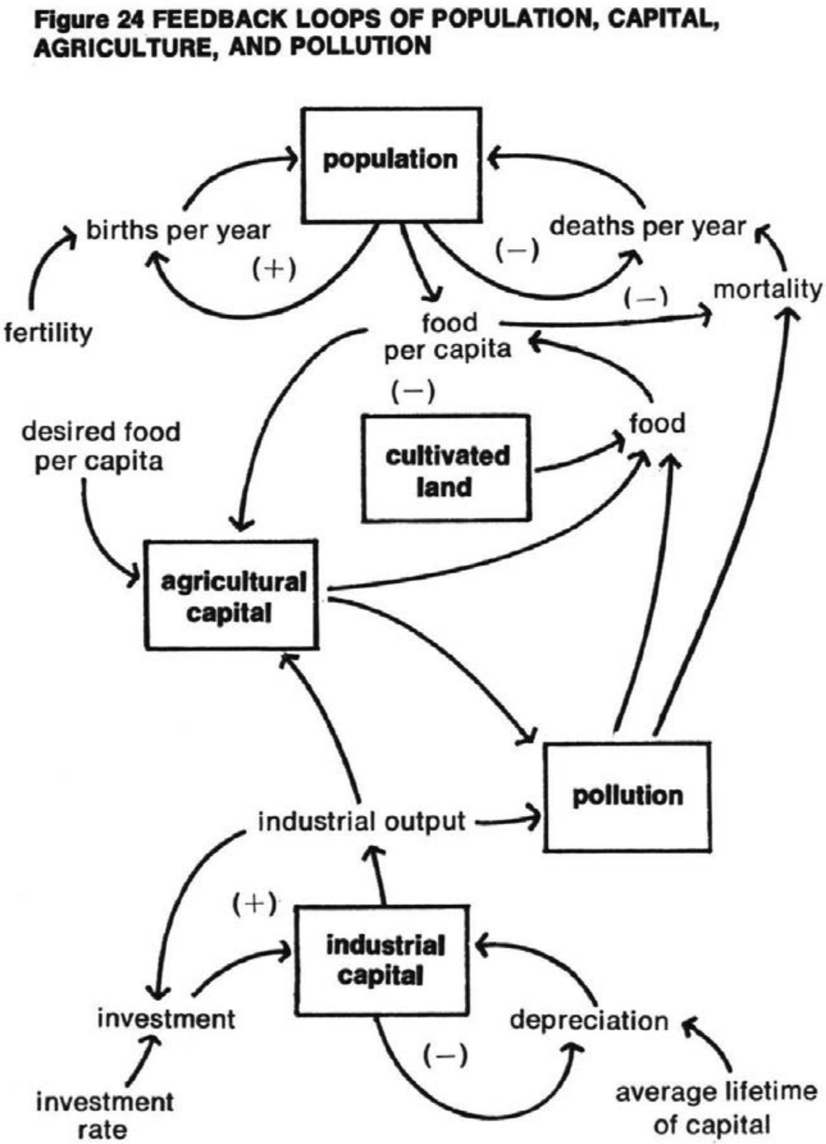
4.6 Howard Odum's model of the Vietnam War. *Source*: Howard T. Odum, *Systems Ecology: An Introduction*, ed. Robert L. Metcalf and Werner Stumm (New York: John Wiley & Sons, 1983), 552.

from this perspective, not thinkable as anything other than a slide toward entropy. Yet it was not clear how such a perspective could take into account the view of some ecologists that many ecosystems did *not* appear to stabilize after suffering disruption. Simply ending the use of a toxin or reseeding an environment, for example, often did not return the system to its past state, and even seemingly environmentally friendly actions, such as lowering fishing quotas or replanting trees, had little effect once certain levels of disruption to the ecosystem were surpassed.[23] Even more problematic, it was not clear how the homeostasis view could deal with the fact that massive disruptions to regular ecosystem behavior—whether from human technologies such as DDT or nuclear blasts, or in the form of past "natural" mass extinction events—were, though extreme, nonetheless relatively standard natural events, at least when one considered long enough timescales. These facts suggested that systems might be *naturally* volatile. Though Odum's ecosystem ecology could only view these facts through a negative lens, some ecologists wondered whether change could be understood as a potential, a source of value, and a necessary activity in nature.

The first of these implications of Odum's approach was evident in *The Limits to Growth*, while the second set of implications was developed in critiques of that report.[24] As we noted in chapter 1, the computational dimension of *The Limits to Growth* was led by Jay Forrester, a pioneer in systems thinking and the design of large-scale computer systems. Forrester worked at MIT to develop the first large-scale computer systems, such as the Semi-Automatic Ground Environment for antiaircraft and nuclear defense, and he had subsequently applied computing to a range of social and human science problems, such as managing industrial supply chains and urban design. While returning home in a plane after a meeting in 1970 with the Club of Rome group in Bern, Forrester sketched a flowchart diagram of the "world system" since the year 1900 and afterward received funding to create a simulation that would model the world system's possible futures.[25] Closely replicating the type of diagrams produced at the time by figures such as Odum, Forrester drew the world in terms of flowcharts and computer programs.[26]

Donella H. Meadows, the lead author of *The Limits to Growth*, remembered Forrester's contribution as stressing that the key problem facing the world was "*growth*—exponential growth of energy use, material flows, and population against earth's physical limits. That which all the world sees as the solution to its problems is in fact a cause of those problems."[27] At a 1968 meeting of the Organisation for Economic Co-operation and Development in Bellagio, which included many future members of the Club of Rome (and also Forrester), Hasan Ozbekhan, director of planning at the System Development Corporation, suggested that humankind was facing "Continuous Critical Problems," which included pollution, poverty, and racial discrimination.[28] What made these problems difficult to address was the human inability to think systemically and globally. Problems seemed to have no limits, but human thinking did. *The Limits to Growth* sought to solve some of these problems via computing, suggesting that while humans simply could not comprehend scale or nonlinear growth, machines and their models were able to do so (figure 4.7).

As we noted in chapter 1, *The Limits to Growth* sold millions of copies, and its success underscored the extent to which a global public was open



4.7 Imagining world problems through feedback loops. *Source*: Donella H. Meadows et al., *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind* (New York: Universe Books, 1972), 97.

to its message about system limits, the dangers of surpassing those limits, and the protocols of computational modeling of the world system. The report relied on a widespread mood, developed since the end of the Second World War, that the world was on the brink of catastrophe. The threat was initially that of nuclear weapons, which produced the first large-scale imaginary of a terminal end of the human species. This threat was channeled into a contest of the warring ideologies of the Cold War, which positioned the planet as a closed space, within which only communism or capitalism could emerge as the sole winner.[29] In the 1960s, texts such as Paul Ehrlich's *The Population Bomb* added a second fear—namely, that the newly decolonized Global South and its imagined masses of population would deplete the resources of the world. Postcolonialism suggested the possibility of a world split into fragmented and warring entities, some of which were armed with new strategies of both subversion and population. Major foundations, including the Ford and the Rockefeller Foundations, as well as the US government through the United States Agency for International Development organization, devoted millions of dollars for programs aimed at studying population management and control in the Global South. Americans especially came to understand international population control and management as crucial to ensuring their health and well-being.[30]

The emergence of an environmental consciousness through the work of ecologists such as the Odums illuminated a third threat. Insecticides such as DDT, fertilizers, and other industrial products seemed able to disrupt natural ecosystems, and the fact that many of these were initially military technologies only augmented the sense of impending disaster. The environment itself had become a war zone, even if the "adversary" to be fought on this field was not quite clear; the conflict was diffused into a worldwide network of environment; and the fields of battle were the territories of biodiversity and the management of biological production and reproduction. Drawing together these multiple threats, *The Limits to Growth* amplified an already existent European and American sense of threat that bound together population, environmental, and political issues and that, it seemed, could only be addressed via the instantiation of some sort of homeostatic "steady state" for the world system.

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Yet this emphasis of the Club of Rome and ecologists such as Howard Odum on homeostasis also provided impetus to a quite different emergent discourse that we label *resilient hopefulness*. While this discourse was as technocratically optimistic as the Club of Rome and Odum, it understood "limits" quite differently. Where Odum and the Club of Rome employed computation in order to produce purportedly objective knowledge of those limits beyond which systems could not function, the discourse of resilient hopefulness employed a new epistemology, one that emphasized that uncertainty could never be eliminated. It thus also pointed to a new technology of *management* that aimed not at control but rather at resilience in the face of endemic shocks. We can observe the emergence of the discourse of resilient hopefulness in two fields that had an especially strong stake in the uptake of *The Limits to Growth*: economics and ecology.

HAYEK, FRIEDMAN, AND RESILIENT MARKETS

Since the stability of the post–World War II international system of Western-style democracies had been premised on the constant economic growth of national economies, economists were likely to be concerned by a report that advocated, on ecological and demographic grounds, for an end to growth.[31] For many economists, this implied that one would have to choose between ecological stability or political stability; one could not have both. In his 1974 speech for his Nobel Memorial Prize in Economic Science award, the economist Friedrich Hayek disparaged *The Limits to Growth* as part of a general plea, addressed to both mainstream economists and their leftist critics, for a more modest epistemology that would give up on the dream of complete knowledge of and control over the future. Hayek noted drily that the recent creation of the Nobel Prize in Economic Science was itself testimony to the "propensity [of economists] to imitate as closely as possible the procedures of the brilliantly successful physical sciences" but stressed that, in economics, this often "led to outright error." Hayek stressed that economies were *not* equivalent to the isolated systems of physics. This was in part because a social science such as economics focused on the behavior of large populations of different agents, with the result that

> like much of biology but unlike most fields of the physical sciences, [economics has] to deal with structures of *essential* complexity, i.e. with structures whose characteristic properties can be exhibited only by models made up of relatively large numbers of variables. Competition, for instance, is a process which will produce certain results only if it proceeds among a fairly large number of acting persons.[32]

Rather than pretending to be able to replicate the kinds of discoveries about the natural world available to physicists, economists should instead accept a biology-like world of uncertainty, chance, and large populations of different individuals. This would mean relinquishing the goal of *planning* and turning instead to the more modest goal of *managing*. For Hayek, societies emerge from decentralized networks of information coordinated through markets, which meant that seeking to plan or regulate the economy—by, for example, limiting or eliminating growth—could only end in disaster.

Hayek suggested that mainstream economists, by seeking to emulate the physical sciences, had in fact given encouragement to precisely that fantasy of control he saw as central to *The Limits to Growth*. He suggested that

> it is often difficult enough for the expert, and certainly in many instances impossible for the layman, to distinguish between legitimate and illegitimate claims advanced in the name of science. The enormous publicity recently given by the media to a report pronouncing in the name of science on *The Limits to Growth*, and the silence of the same media about the devastating criticism this report has received from the competent experts, must make one feel somewhat apprehensive about the use to which the prestige of science can be put. But it is by no means only in the field of economics that far-reaching claims are made on behalf of a more scientific direction of all human activities and the desirability of replacing spontaneous processes by "conscious human control."[33]

For Hayek, systems self-organized from the "free efforts of millions of individuals" and not the conscious decision-making power of the few. As a consequence, control—understood as predicated on the prediction of future events, whether by mainstream economists or the Club of Rome—was impossible. For Hayek, though, this was not cause for despair. Rather, it was grounds for hope, provided that those populations of millions were allowed to engage new and unanticipated problems flexibly by means of unrestricted market activity.

Hayek's lecture focused primarily on the rather abstract realm of epistemology and provided relatively little guidance as to what this approach might look like in practice. However, in the 1970s several economists and ecologists turned to concepts of flexibility and resilience to explain how the epistemological modesty valorized by Hayek could generate solutions to specific new and unanticipated problems while at the same time avoiding system collapse. Within international relations, one such problem was the failure of the Bretton Woods international currency exchange system in the late 1960s and early 1970s. The Bretton Woods system was designed shortly after World War II and was supposed to keep Western economies stable by preventing large international currency exchange rate fluctuations, which many economists and policy analysts saw as one of the key causes of the rise of Fascist and totalitarian regimes after World War I. However, the system—which pegged international currency rates to the US dollar and the US dollar to a fixed gold exchange rate—was having serious problems in the 1960s and finally ended in 1971, when President Richard Nixon declared that the US dollar could no longer be exchanged for gold.

Chicago School neoliberal economist Milton Friedman saw in the collapse of the Bretton Woods system an opportunity for creating a new, resilient system of international currency exchange. In a 1971 article titled "The Need for Futures Markets in Currencies," Friedman acknowledged that, in the absence of an international system of currency controls, exchange rates would shift constantly in relationship to one another. The architects of Bretton Woods had seen such volatility as a problem since it meant that those engaged in foreign trade would have to take significant risks that the currency in which a trade was negotiated would depreciate by the time payments were to be made. Bretton Woods thus sought to institute a "system of rigidly fixed [exchange] rates that do not change." However, as Friedman noted, they ended up with a "system of rigidly fixed rates subject to large jumps from time to time," and these large jumps eventually broke what was designed to be a rigid system of control.[34] Friedman argued that the solution could not be another rigid centrally controlled system but instead a resilient futures market for currencies: that is, there was a "major need for a broad, widely based, active, and resilient futures market" that would allow those engaged in foreign trade to hedge the risks associated with currency exchange changes.[35]

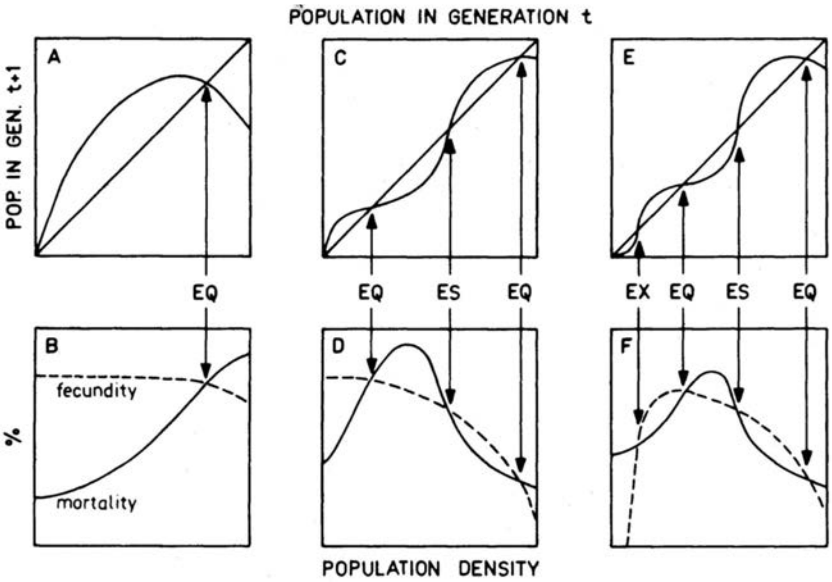
For Friedman, "resilience" was to be understood as the opposite of "rigidity," and would mean, in practice, something like the oxymoronic notion of "stable change." More specifically, currency markets would change in response to global events but nevertheless continue to protect international trade, the international global political order of the West, and the primacy of the United States within that order. Although Friedman was presumably one of those economists chastised by Hayek in his lecture as overly committed to "scientific" models of economics, Friedman's proposal for resilient futures markets nevertheless exemplified Hayek's image of markets that flexibly managed, rather than rigidly controlled or planned, an always uncertain future.

HOLLING, ECOLOGY, AND RESILIENCE

The terminology of resilience was also at the center of a new discourse in ecology, one that subtly contested both Howard Odum's commitment to homeostasis and the implementation of that vision in *The Limits to Growth*.[36] Ecologist C. S. Holling began his 1973 essay "Resilience and Stability of Ecological Systems" with a contrast between two ways of looking at the world:

> INDIVIDUALS DIE, POPULATIONS DISAPPEAR, and species become extinct. That is one view of the world. But another view of the world concentrates not so much on presence or absence as upon the numbers of organisms and the degree of constancy of their numbers. These are two very different ways of viewing the behavior of systems and the usefulness of the view depends very much on the properties of the system concerned.[37]

Odum and the Club of Rome valorized a world without change (i.e., stability) and so understood change only as either the movement toward stability or the first step toward collapse and catastrophe. Holling, by contrast, sketched a view of the world in which change—even catastrophic change—is the norm. Yet, Holling proposed, such change leads not to the end of systems but rather to their evolution. Changes may indeed cause some species to go extinct, yet systems themselves, "degrees of constancy," and evolution persist. Holling used the term "resilience" to capture this latter capacity of systems (figure 4.8).



4.8 C. S. Holling's diagrams speculating on various "futures" for population reproduction curves and deriving fecundity and morbidity (*bottom row*) from these curves. *Source*: C. S. Holling, "Resilience and Stability of Ecological Systems," *Annual Review of Ecological Systems* 4 (1973): 1–23.

Holling based his new term, "resilience," on a number of ecological facts that Odum's systems approach had difficulty incorporating. In an early critique of then-current models of industrial fishery and forestry management, Holling demonstrated that using insecticides, reseeding lakes with fish, or replanting one type of tree did not in fact return ecological systems to an earlier, purportedly stable state. Holling's research on budworm infestations that destroyed economically valuable softwood forest stands (conducted while he was employed by the Canada Department of Forestry in Sault Ste. Marie, Ontario) led to an even more startling conclusion.[38] The spruce budworm is a small defoliating insect that had plagued the boreal forests of North America in periodic episodes for centuries. In response, in 1951 the Canadian province of New Brunswick initiated an insecticide-spraying program. In the short term, this successfully reduced tree mortality. Yet these efforts did not appear to work in the long term. Using historical data from 1951 to the early 1970s, Holling's group discovered that forests went through cycles of fluctuating populations, changing their entire state and character over longer sweeps of history; that is, there is no one "apex ecology," for forests constantly shift among dominance of spruce, birch, and balsam fir trees (figure 4.9). Under natural conditions, budworms contribute to this process of change. It was in part the *tree industry's preference* for one type of tree over another that encouraged the notion of an "ideal" state of the forest that should remain stable.[39] Holling's computational modeling of the historical time series also suggested that tactics intended to maintain this ideal state, such as the use of insecticide, actually increased the area of the forest vulnerable to incipient outbreak conditions. In other words, attempts to maintain stability were, over the long term, counterproductive since they extended vulnerability and the possibility of future outbreaks over larger territories.

Managing ecosystems with a focus on stability was, in short, an error. Efforts to distinguish taxonomically between populations, count the size of each population, and place these numbers in flowcharts of linked boxes that retained their form because they were connected to one another by processes of negative feedback fundamentally misunderstood the nature of ecologies. Positive, rather than negative, feedback was the central concern for Holling's approach to system modeling, for positive feedback produces dynamism and change. This emphasis on change suggested to Holling that one must think of ecologies not primarily in terms of their resident populations but in terms of the *processes* or *services* that an ecology provides. What, in fact, does a forest *do*? Does it provide trees? Shade? Hatching grounds for other species? These processes were the central elements of ecologies, and these processes had to be distinguished from the numeric counting of populations, however important the latter might also be. If humans wanted to manage forests, they had to seek to maintain these processes, rather than simply a specific number of individuals in a population.

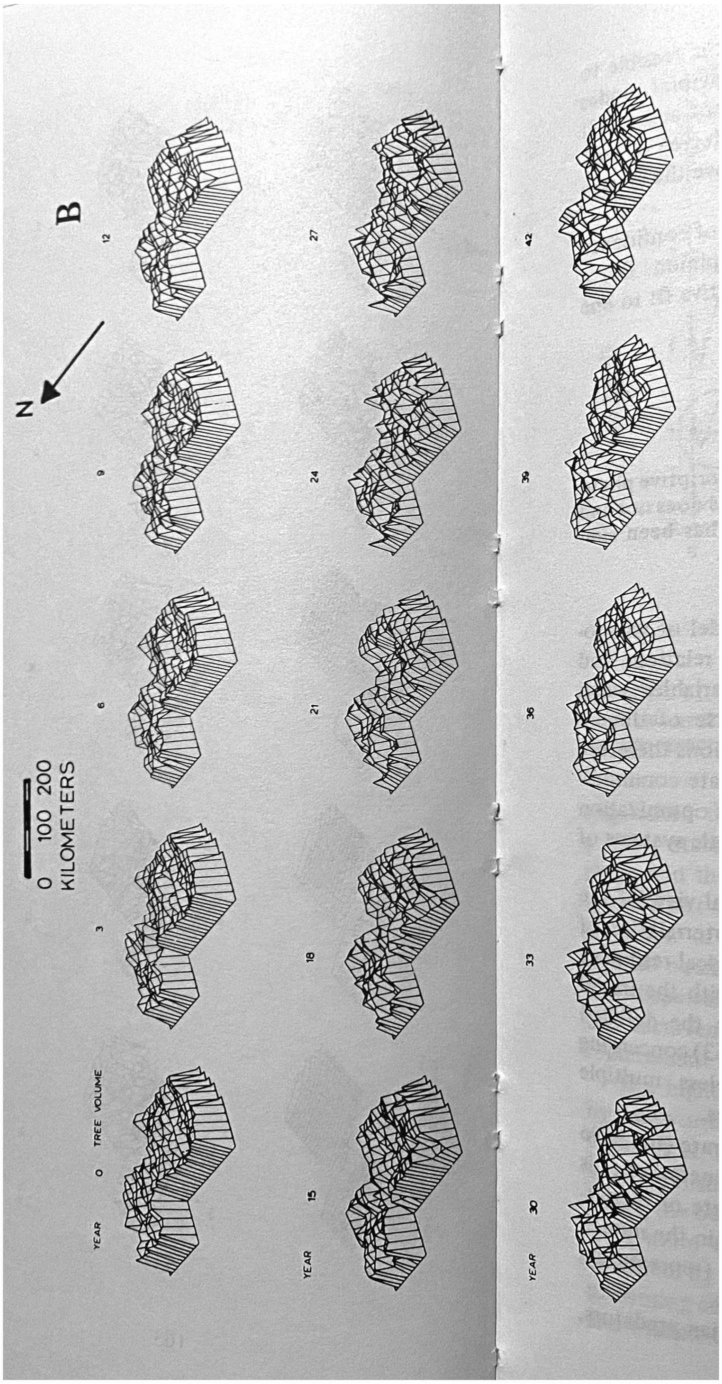
In the case of the forest in the budworm studies, for example, Holling suggested that the absolute number of spruces is not important. What *is* important is the ability of the forest to rejuvenate and to continue growing trees, and this capacity depends upon fluctuating numbers within specific tree and insect populations. Better ecological management meant understanding that systems change: forests in Ontario, for example, might be used for some time for leisure and vacationing and then for forestry, and their management must change accordingly. As we note in more detail below, Holling described this as "adaptive management" and argued that while this approach necessitated constant gathering and analysis of data, the goal of data gathering was not to locate deviations from a stable state but to enable managerial goals and methods to change in response to a constantly changing ecology.[40]

If in the 1940s and 1950s the nuclear bomb and its fallout had provided a new way to visualize ecological relations, by the late 1960s contamination of the environment made it possible for ecologists such as Holling to reenvision those relations not in terms of stability but in terms of constantly mutating systems. Resilience denoted for Holling the capacity of a system to persist by changing in periods of intense external perturbation. The concept of resilience enabled a management approach to ecosystems that "emphasize[s] the need to keep options open, the need to view events in a regional rather than a local context, and the need to emphasize heterogeneity."[41]

In order to secure more possible routes for adaptation in case of unanticipated shocks, environmental managers had to create multiple strategies for future action, think "regionally" (that is, in terms of networks and connections across different territories and times), and emphasize heterogeneity (e.g., biodiversity).[42] Resilience was defined in relationship to crisis and states of exception; as we noted in the introduction to this book, resilience can be a virtue only when crises are assumed to be either quasi-constant or the most relevant issue for managerial actions. Holling underscored that the movement from stability to resilience required an epistemological shift: "Flowing from this [emphasis on resilience] would be not the presumption of sufficient knowledge, but the recognition of our ignorance: not the assumption that future events are expected, but that they will be unexpected."[43]

Seeing the world through the lens of resilience meant not only expecting the unexpected but also employing the unexpected as occasions for *learning*. As Holling noted,

> Efforts to reduce uncertainty are admirable. . . . But if not accompanied by an equal effort to design for uncertainty and to obtain benefits from the unexpected, the best of predictive methods will only lead to larger problems arising more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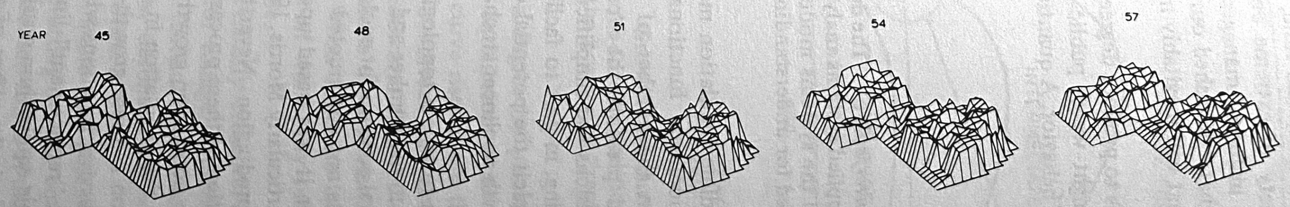

FIGURE 11.8 Spatial behavior of the budworm–forest model under historical harvest and spraying rules. The coordinates are as defined for Figure 11.7. The orientation and scale of Figure 11.8A are the same as in Figure 11.8B. Figures 11.8A and 11.8B show patterns of egg density and tree volume, respectively, beginning with conditions known to exist in 1953. Compared to Figure 11.7, the management policies can be seen to preserve trees, but at the expense of creating permanent semioutbreak conditions, highly sensitive to policy failure.

4.9 Topological models generated from historical data since 1951 of budworm population densities in space. It is also worth noting that these new dynamic maps and capacities to compare data sets came with the introduction of digital computation and new platforms such as the Canadian geographic information system (CGIS), considered the root of contemporary GIS systems in the early 1970s. *Source*: C. S. Holling, "The Spruce Budworm/Forest Management Problem," in *Adaptive Environmental Assessment and Management*, ed. C. S. Holling (New York: John Wiley & Sons, 1978), 143–183.

quickly and more often. This view is the heart of adaptive environmental management—an interactive process using techniques that not only reduce uncertainty but also benefit from it. The goal is to develop more resilient policies.[44]

Adaptive management was a method for transforming ecology into engineering while at the same time transforming engineering into an adaptive learning process—or, in Papanek's terms, channeling the human capacity for alloplasticity into environmental management.

As our reference to Papanek underscores, Holling's theory of resilience was in one sense simply symptomatic of larger shifts in ideas of evolution, as applied to both nature and culture, that occurred in the 1960s and 1970s. For example, new theories of evolutionary change, such as the Gaia theory developed by chemist James Lovelock and microbiologist Lynn Margulis in the early 1970s, focused on the capacity of living organisms to metabolize the geological, energetic, and chemical materials of the earth to induce climatic change. Breaking down the clear separation between the geological and the organic, Gaia theory was predicated on regular extinction events and massive pollution scenarios as one microbe or geological event after another transformed the environment into an inhospitable milieu for fellow organisms. Yet despite the regularity of massive extinction events, "life" persevered and constantly evolved, and was in this way always able to reformulate environments.[45] Holling's emphasis on epistemological modesty was echoed in Hayek's market theory, while economists such as Eugene Fama sought to demonstrate in the 1970s that extreme volatility and so-called fat tail distributions were much more common in financial markets than would be predicted by theories that presumed a steady state normal curve in market growth.[46] Holling was, from this perspective, simply one of many who contested the view that economy, culture, and life were characterized by stability.[47]

If we have focused on Holling's theory of resilience, it is because this theory, especially its implementation within the practice of adaptive management, has proven to be especially important in drawing together the seemingly separate realms of ecology and economics. We will expand on Holling's key notion of adaptive management in the next section, but before doing so we want to make three summary points about resilience.

The first is that because resilience assumes uncertainty and volatility as our common, perhaps even "normal," condition, the life and death of specific individuals or even populations is in principle less important than the ongoing evolution of systems. Second, resilience refers to a new way to model systems and therefore to define and measure their elements. Instead of developing taxonomies that enable ecologists to organize populations into stable categories, resilience encourages ecologists to define systems in terms of processes and to measure the relationships *between* populations and other factors (nitrates, carbon, energy, and so on). A first corollary of this second point is that the techniques designed for ecological management also apply to human systems since there is no hard and fast distinction between these two kinds of systems.[48] A second corollary of this second point is that past data can be used to build concepts and encourage experimentation but can never actually predict the future. Our third point is that ecologists interested in resilience emphasize heterogeneity and diversity as important to facilitating resilience. Systems without a *surplus* of functions and populations cannot adapt. Perfectly optimized systems would collapse when faced with change—and the latter was inevitable.

There are tensions among these summary points. On the one hand, the focus on processes and what today are called *ecosystem services* necessarily means that some lives and populations can be acceptably sacrificed so long as the system continues to operate; in this sense, trauma is a regularized and normalized event. (In later ecological work on hierarchies and models of ecosystems, ecologists often prioritized "key" species or relationships in order to make the model operative.[49]) On the other hand, environmental managers recognized that only systems with robust diversity, redundancy, and supplemental capacities might survive abrupt and catastrophic events—which meant, when combined with Holling's emphasis on epistemological modesty, that it was impossible to know in advance which lives and populations were "actually" disposable. Resilience thus oscillates between the two poles of Darwinian evolutionary theory: on the one hand, survival of the fittest; on the other, the need for diversity within and between populations in order to enable adaptability. *Optimization* of the system always potentially comes at the cost of adaptation. This means, though, that ecology can contest contemporary forms of artificial intelligence grounded in the assumption that improvements always occur through optimization of the "fit" of solutions to a representable model.

ADAPTIVE MANAGEMENT

Holling's new understanding of ecological systems as made up first and foremost of services (rather than, say, populations), his emphasis on epistemological modesty, and his stress on enabling resilience for an always uncertain future brought his vision of ecology quite close to the neoliberal understanding of markets. It is thus perhaps not surprising that Holling's understanding of resilience has spread far beyond ecology proper and has become central to disaster management, design thinking, humanitarian aid, governmentality, and infrastructural security; in addition, his related concept of adaptive management has moved outward from ecology to fields such as business and urban design.[50] By 2007, Holling himself had become a central figure in both environmental policy and business management circles, not least because of his work founding the Stockholm Resilience Center, a major university and international science advisory council that encourages research on resilience and socioecological systems, works closely with numerous United Nations branches, and develops initiatives for the global seafood industry.[51]

While other scholars have noted the spread of concepts of resilience from ecology into other fields, they have generally not focused on the extent to which Holling's distinctive approach to data gathering, computer modeling, and *scenarios* have been part of that package. We want to stress this point, for it is the roles of data and model building for adaptive management that have made the latter especially important to the development of smartness and the smartness mandate. In his field-defining textbook, Holling urged ecological managers to accept that "comprehensive 'state of the system' surveys (species lists, soil conditions, and the like)" are *not* "a necessary step in environmental assessment." Holling stressed that

> survey studies are often extremely expensive yet produce nothing but masses of uninterpreted and descriptive data. Also, they seldom give any clues to natural changes that may be about to occur independently of development impacts. Environmental systems are not static entities, and they cannot be understood by simply finding out what is where over a short survey period.[52]

Moreover, ecological management encompassed for Holling both social and environmental features that are difficult to define and which therefore escape the earlier and static models of ecosystem ecologists such as the Odums.[53]

In order to negotiate these limits of large data sets, two practices began to emerge within both ecology and business management. On the one hand, managers moved away from the goal of predicting the future and instead adopted methods of scenario planning for extreme events. In his foreword to Holling's *Adaptive Environmental Assessment and Management*, environmental manager Martin Holdgate echoed Hayek's critique of efforts to *predict* the future, contending that in the case of environmental studies, "much effort has been devoted to . . . collection of unnecessarily large quantities of data that have given rise to undue expectations and unsatisfactory predictions."[54] Holling and his colleagues argued that though large data sets are often necessary for effective environmental management, such data should be used to create models that are understood from the outset as partial and always in need of future refinement (or even abandonment). Models enable the development of multiple scenarios of the future, but the intuitive plausibility of these scenarios can also be used to contest aspects of the model.[55] Whether Holling and his colleagues drew the term "scenario" from Cold War planners such as Herman Kahn, their approach paralleled the development in the late 1960s and early 1970s of scenario-planning divisions within major corporations such as Royal Dutch Shell. These corporate divisions also emphasized the impossibility of predicting the future and the importance of using scenarios recursively as a means of allowing companies to learn and adapt to changing conditions.[56]

There is a significant distance between Holling's vision of fallible scenarios and the models of the future provided in *The Limits to Growth*. Meadows and her colleagues also stressed that their "graphs are *not* exact predictions of the values of the variables at any particular year in the future" and noted that the model could and should be refined as more data was gathered.[57] At the same time, Meadows and her coauthors stressed that *their model itself* was complete, in the sense that it accurately captured and revealed the world system's "behavioral tendencies":

> Even in the absence of improved data, information now available is sufficient to generate valid basic behavior modes for the world system. This is true because the model's feedback loop structure is a much more important determinant of overall behavior than the exact numbers used to quantify the feedback loops. Even rather large changes in input data do not generally alter the *mode* of behavior, as we shall see in the following pages. Numerical changes may well affect the *period* of an oscillation or the *rate* of growth or the *time* of a collapse, but they will not affect the fact that the basic mode is oscillation or growth or collapse.[58]

Additional data would thus enable only a refinement, rather than a fundamental disqualification, of the report's model itself.

Adaptive management (and scenario planning) contested precisely this belief in the unquestionable validity of the model. Adaptive management thus sought to study and collect data on *management systems themselves* in order to develop more complex models of their operations so that this understanding could be fed back into, in order to improve, management principles. Resilience managers must bring together better knowledge about how systems survive stress with an awareness that elements of systems will always escape current models. As the limit points of computational analysis and prediction, scenarios not only described possible futures but also served as a constantly shifting and new frontier for calculation. The scenario was both what one could not in fact model but could only guess at intuitively, and what ongoing efforts at data gathering and feedback models must constantly seek to capture.

Principles of adaptive management have been integrated into many contemporary business practices, often by merging with practices that have different genealogies. In his work on business continuity management (BCM), for example, Andreas Folkers demonstrates how notions of ecological resilience entered business management and informed disaster and catastrophe preparedness in the case of the financial sector.[59] Folkers notes that BCM

> is a nascent disaster preparedness and recovery strategy that is mostly applied in the private sector. It seeks to ensure the continuous functioning of the most fundamental business processes in the face of various emergencies. It involves establishing redundant infrastructures like relocation sites and back-up systems, as well as the preparation of emergency protocols to enable swift and effective responses to disruption. BCM is a generic risk management strategy, but it is especially prominent in the finance sector. This is because 9/11 not only heightened awareness of the importance of proper disaster response strategies in the financial sector, but also highlighted the shortcomings of existing incident management strategies.[60]

Folkers notes that though the genealogy of *continuity planning* can be traced back to Cold War efforts to ensure the persistence of government and government services in the event of nuclear war, this aspiration was then linked to concepts of resilience in the early 2000s. If adaptive management aims to enable *learning with continuity*, BCM is focused on ensuring the continuity side of that aspiration.[61]

The principles of BCM were made stunningly visible in 2012 when the Category 3 hurricane Sandy hit the New York metropolitan area. The storm devastated the infrastructure there, leaving almost 10 million people literally in the dark. Infrastructure damage was particularly intense in minority and Black neighborhoods, as well as public housing projects in zones such as Red Hook in Brooklyn.

Yet in the midst of the storm, a single gleaming building in Manhattan *did* have power, despite the outages everywhere else. That building was investment bank Goldman Sachs, one of the major financial institutions in the United States. Its ongoing operations were both in support of and an example of adaptive management tactics cultivated after September 11, 2001, to ensure the ongoing operation of its financial services. If one were to imagine the ecosystem services of lower Manhattan, it is clear that—at least in the vision of certain planners and engineers—*finance* is the key service, and much of the rest of the city can essentially be sacrificed to maintain the continuity of this function. Goldman Sachs's continuity managers are, in any case, more concerned with continuing services than anticipating the specific disaster that might strike the city. Continuity management aims to overcome logistical challenges, and over the last decade, Goldman Sachs has issued a business continuity statement that announces its preparedness through the triage of personnel; redundancy in servers and data infrastructures; dispersal across sites for archiving and service functions; and emergency electrical and building management systems, to name a few of their measures.[62]

The BCM practices of Goldman Sachs and other companies are marked by the absence of the state, and the geographic dispersal of these strategies across multiple national borders. Resilience continuity management demands the dispersal of activities into different zones of legal regulation, weather, energy, and geological stability to ensure the safety of its information networks and services. This is quite distinct from the spatial centralization of the Cold War bunker system. The continuity strategies of Goldman Sachs and other companies underscore a shift to the mode of vital systems security that has become dominant since the early 2000s and which is characterized by a disinterest in causal prediction in favor of all-purpose strategies of ensuring continuity—and, whenever possible, using disasters as occasions for further learning about how the corporate structure can better manage future disasters.[63] Resilience thus also participates in that zonal reformulation of territory in the name of experimentation that we described in chapter 2.

The recent concept of business *antifragility* developed by popular financial writer and sage of uncertainty Nassim Taleb is another example of adaptive management and resilience. While Taleb criticizes the specific way in which the term "resilience" has been employed by economists, his notion of antifragility is remarkably similar to the concept of ecological resilience developed by Holling. For Taleb, antifragility names the ability of organizations and organisms to gain strength from stress and shock. Taleb suggests that the awkwardness of his term "antifragile" underscores that there is no existing word for this concept in most languages. He claims, though, that this concept that describes a dynamic that we can observe in natural evolutionary processes:

> The most interesting aspect of evolution is that it only works because of its antifragility; it is in love with stressors, randomness, uncertainty, and disorder—while individual organisms are relatively fragile, the gene pool takes advantage of shocks to enhance its fitness. So from this we can see that there is a tension between nature and individual organisms.[64]

Evolution is radically uncertain. However, like ecologists and Goldman Sachs, adaptive managers can understand and produce new measures. As Taleb explains, antifragile managers—or, as we would put it, managers oriented toward resilience—constantly and actively measure error:

> Fragility can be measured; risk is not measurable (outside of casinos or the minds of people who call themselves "risk experts"). This provides a solution to what I've called the Black Swan problem—the impossibility of calculating the risks of consequential rare events and predicting their occurrence. Sensitivity to harm from volatility is tractable, more so than forecasting the event that would cause the harm. So we propose to stand our current approaches to prediction, prognostication, and risk management on their heads. In every domain or area of application, we propose rules for moving from the fragile toward the antifragile, through reduction of fragility or harnessing antifragility. And we can almost always detect antifragility (and fragility) using a simple test of asymmetry: anything that has more upside than downside from random events (or certain shocks) is antifragile; the reverse is fragile.[65]

Taleb suggests that stress tests, failures, and simulations do not necessarily discover specific future risks but rather enable us to assess, and mitigate, systemic fragilities. As in the case of Holling's adaptive management and Goldman Sachs's business continuity plans, big data operate in Taleb's antifragility planning not in the service of imagining and instantiating specific futures but rather in consolidating and extending aspects of the present into the future.

Excursus 4.1
The East Kolkata Wetlands

The megacity of Kolkata, West Bengal, India, lies on the floodplains of the Hooghly River at sea level (figure 4.10). One of the largest and densest settlements on earth, the city was central to the development of capitalism and has long been at the heart of global trade and commerce. Kolkata was also a massive terraforming project for imperial and capitalist concerns. In search of wealth from saltpeter, opium, salt, silk, cotton, jute, tea, and rice, the British East India Company first transformed the silt and protective wetlands of the area into a logistical center through the creation of this riverine port in the late eighteenth century.[66]

This transformation of nature into real estate also inaugurated one of the world's great pandemics. Cholera bacteria lived untouched and untroubled inside small snails at the bottom of the river. When the East India Company's dredges uprooted these snails, and with them the bacteria they sheltered, they

4.10 Rajarhat, district 5, New Town, Kolkata, India. *Source*: Photo by Orit Halpern, March 13, 2016.

4.11 East Kolkata wetlands. (a) Fish farming. (b) Real estate speculation and high-end luxury development. *Source*: Photos by Sudipto Basu, October 4, 2021.


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Excursus 4.1 (continued)

unleashed cholera into human populations. By the early nineteenth century, the first cholera outbreaks were reported in Europe. The pandemic continued for decades, becoming one of the most lethal pathogens afflicting human populations.

The wetlands of West Bengal have in this way long served as both sites of speculation and ecological catastrophe (figures 4.11a and 4.11b). Today, these silts and wetlands are rapidly being converted into shiny office towers in the search for smartness. The fancy peri-urban new and smart cities of the region, such as Rajarhat, Salt Lake City, and New Town, all tout slogans of a clean "atmosphere," of green construction, green corridors, and smart services and buildings. New Town, one of the shinier greenfield suburbs being constructed, has even recently been ordained by the Ministry of Housing and Urban Affairs as the "eighth most intelligent" of India's 100 smart cities. It has been certified and identified as "enabled" by an instrument labeled the *data maturity assessment framework 2.0* that measures how much data is put online.[67]

Bengali state planners hope for growth and innovation in Kolkata's technology sectors, which is lagging in comparison with other regions in India, by means of new developments on the former wetlands. While much of the new housing in Rajarhat, as well as in its nearby New City and Salt Lake developments, is underoccupied (having been bought for speculation by domestic and foreign investors), construction continues ahead at full speed on luxury condos and office parks. These spaces are highly leveraged and derived, conjoining joint imaginaries of smart and greenfield cities fostered by the Indian government and Bengali planners with derivative actions of global finance capital.[68] Whether these aspirations for smartness are realized or not, the developments, including a new Trump Tower, are commencing at a frantic pace. At the same time, some 30,000 people (as of 2016; the current total is surely much higher) have been displaced by the past decade of development.[69]

This search for real estate to build smart cities is, however, happening on top of the city's alternative infrastructures for resilience and life. Kolkata is perhaps the only city of its size on earth that has no wastewater treatment facilities. In the 1980s, sanitation engineer Dhrubajyoti Ghosh was asked by a finance minister to investigate the sewage treatment situation in Kolkata. He realized there was none. Instead, he discovered something long known to local fishermen and denizens (not to mention the millions eating the fish)—namely, that a system of aquatic agriculture dependent upon the local algal ecology was conducive to degrading wastes and could serve multiple functions. Seemingly miraculously, a city of 14.5 million inhabitants, 70 percent of whom live in poverty, has its water fairly effectively recycled and cleaned by a wastewater aquaculture area called the East Kolkata Wetlands (EKW).

The EKW help feed a city in which the majority of the population lives in poverty, provide cheap and energy-free sewage treatment, and—equally important—serve as one of the most important ecosystems and ecologies for flood defense in the face of climate change. The Rajarhat area in the wetlands

AU: Normally we try to place the figures following where they are mentioned in the text, but since figures 4.11a and 4.11b needed to be placed on facing pages, that wasn't possible here (they appear on pages 204 and 205).

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Excursus 4.1 (continued)

also contains aquifers crucial for the water recharge of the entire delta and may maintain the hydrological equilibrium of large amounts of the subcontinental watershed. It is also a biodiversity hot zone.

The demise of the EKW to make way for smart buildings and infrastructure puts at risk the lives of the poorer denizens of Kolkata, as well as the existence of many nonhuman species. Environmentalists and planners have drawn on the concept of resilience to argue that destroying this area may be the death knell for a city that is one of the most vulnerable in the world to sea-level rise.[70]

Ghosh himself described forms of planning in which consideration of the poor is excluded from urban planning and engineering schemes as "cognitive apartheid.[71] In the past 30 years, many Asian cities turned from wastewater aquaculture to other forms of monoculture agriculture and abandoned wetland methods in the name of higher-technology sewage treatment plants. Kolkata had remained one of the exceptions to this rule. Though in 2002 the EKW was designated a Ramsar site and so is in theory protected under the purview of the United Nations Educational, Scientific, and Cultural Organization, ongoing dispossession—largely achieved through fraudulent means as poor fishing families are bought off—has transformed protected lands into speculative real estate. At the same time, the government touts sustainability and resilience primarily by understanding cities as "engines of growth for the economy . . . setting in

COMP: Transfer figure 4.12 to the top of page 208. Enlarge the figure as needed (to a maximum width of width of 30 picas) so that it better fits the space occupied by the excursus on that page. (PE)

4.12 Floating wetlands, Charles River, Cambridge, MA. *Source*: Photo by Orit Halpern, April 17, 2021.

~~Excursus 4.1 (continued)~~

motion a virtuous cycle of growth and development."[72] These contemporary practices extend earlier postcolonial policies encouraging urbanization and, supposedly, modernization, with smart cities as the next step in this process.

The irony, of course, is that just as the wetlands and their denizens are dispossessed and destroyed in places like Kolkata, wetlands have become central to urban planning in the rich Global North. In cities like Boston, New York, and Miami, the centrality of such designs is becoming increasingly understood as a key feature of smartness (figure 4.12). In these sites, ecosystems are understood to be acting as sensors, data collectors, filters, and nurseries for biodiversity as they protect the surrounding city.

Wetlands in this way highlight both the promise and the peril of smartness. Smartness produces resilience—but for whom or what is such resilience an issue? Smartness reimagines the divides between urban-rural and the hinterlands and the metropolis and creates new understandings of intelligence and knowledge. But it can also be recuperated to justify the destruction and sacrifice of certain lives at the cost of others. The Indian government, in its own search for smartness, has defined this concept broadly: since "there is no universally accepted definition of Smart City" then "the objective [of the smartness initiative] is to promote cities that provide core infrastructure and give a decent quality of life."[73] We agree, but note that in the absence of history and genealogy, the discourses of ecology and resilience are likely to be subsumed within neoliberal economy and environmental management.

RESILIENT REPURPOSED

Each of our earlier examples—adaptive management, BCM practices, and antifragility strategies—instantiates in its own specific ways the more general logic by which smartness combines data gathering, modeling, and planning. Smartness predicates itself on a world assumed to be so complex that it can never be perfectly modeled, which in turn means both that catastrophes must be habitually expected and that one cannot plan for the next *specific* disaster. The logic of smartness thus endorses Paul Virilio's suggestion that we live in the era of the "generalized accident"—that is, an age characterized by catastrophes that are largely human induced yet nevertheless cannot be anticipated in their specifics.[74] The best one can do is to *manage* specific accidents as they arrive. Such management requires ever-increasing data collection within microenvironments, which is then networked in order to avoid the errors of centralized command and control. Within smart city logic, for example, the emphasis is on data-driven planning that can rapidly accommodate climatic, economic, or political change without being burdened by any specific political plans or dynamics.

At the same time, this effort to manage unthinkable futures encourages a constant search for "the long tail" (data that points to extreme and unusual events) since the very logic of planning is understood as inseparable from the temptation to take the norm—that is, what usually happens—for the entire space of possibilities. The assumption that catastrophe must be understood as habitual, so to speak, drives efforts to build technologies that can disperse risks in time and space, whether through the actual construction of diffuse and decentered physical networks or through forms of financial risk management, such as insurance or financial derivatives. All of these technologies require increased environmental calculation and computation, yet this increase of data gathering and technologies is not grounded in a discourse of certainty, causality, or positivism. Donald Rumsfeld, secretary of defense under President George Bush, perhaps put it best in his now infamous dictum that "there are known knowns; there are known unknowns; and there are unknown unknowns." Resilience planning is the means through which systems can prepare for, and (after the fact) learn from, those future unknown unknowns—all of which are, it goes without saying, assumed to be threatening and negative.

Returning to our opening example of COVID-19 curve flattening, these elements of smartness are at the heart of the strategies that governments have used to manage a pandemic that was unanticipated in its specifics but that was also, as we noted, anticipated by public health experts as a possible and even likely future scenario. A search online for "resilience" and "COVID-19" reveals a massive number of articles, websites, and consulting services dedicated to logistics, psychology, and community activism.[75] For managers of supply chains and corporations such as SAP and IBM, corporations must become resilient to ensure business continuity: "just-in-time" manufacturing has now become "just-in-case" manufacturing, and companies are urged to increase their options, to diversify supply chains geographically, to begin thinking about plasticity in manufacturing infrastructure (for example, being able to make alternative products), and to identify vital services and processes ahead of time. The COVID-19 pandemic has also clarified which populations national governments consider "expendable"—generally, the elderly, people with underlying health conditions, and people of color—as politicians seek to contain the spread of infection while at the same time ensuring continuity of the economy. As was especially evident in the response of the Trump administration in the US, resilience can be employed as a means of naturalizing violence by exploiting the uncertainties around a catastrophe—uncertainties, for example, about the precise vectors of transmission (surfaces and airborne respiratory droplets? Droplets only in closed rooms? and so on)—as a rationale for doing nothing (which in fact means allowing disproportionately high numbers of certain populations to die).[76]

Perhaps counterintuitively, though, resilience has also been invoked as a strategy, norm, and aspiration by some of those same groups positioned as expendable within government and corporate strategies of dealing with COVID-19. On the Black Lives Matter website, for example, resilience is imagined as an alternative to the triage logic of the status quo: "We affirm our humanity, our contributions to this society, and our resilience in the face of deadly oppression." Critical race theorist Kara Keeling has drawn on Taleb's related concept of antifragility as a figure of thought for Black liberation and for the possibility of becoming stronger through exposure to ongoing shock. Keeling stresses that Taleb's book itself is a neoliberal treatise and is interested only in the implications of antifragility for commercial entrepreneurialism. Yet she notes that precisely because Taleb's concept of antifragility is a *critique* of the efforts of economists to predict and control future risks through computational and calculative techniques of derivation and commensurability, it can be part of a liberatory strategy. More specifically, Keeling suggests that

> the concept of "antifragility" offers the following to the present project [of her book *Queer Times, Black Futures*] and its investments in freedom dreams: (1) a critique of finance capital's construction of "futures" . . . and (2) another way of thinking about the queerness in time as an ally in building the antifragility of freedom dreams, the obsessive love that sustains them, and those who advance such dreams within, without, and through love.[77]

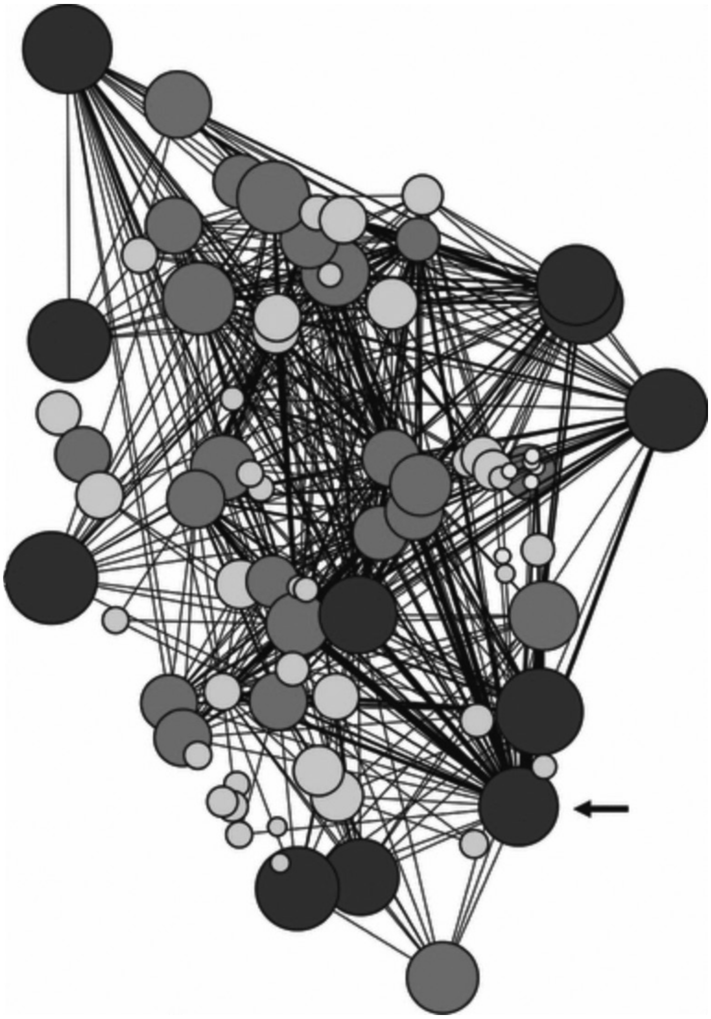
The concept of antifragility is useful to Keeling—and the related concept of resilience is presumably useful to the authors of the Black Lives Matter website—because these concepts focus attention on the connection between thriving and shock. Keeling suggests that "something is antifragile when it thrives rather than breaks in conditions of disorder and randomness," and hence "Taleb's work enables the insight that Black cultures are antifragile. They build accidents and surprises into the modulations that enable them to endure."[78] For Keeling, the concept of antifragility calls for us to understand the future of our present as not yet decided and so as potentially radically different from the present. Keeling's concept of shock thus does not legitimate the sacrifice of lives but rather recognizes that trauma has been ongoing and continuous for Black people and many others. Such trauma, however, not only can be survived but can become a source for creativity and transformation.

Excursus 4.2
Possible Futures of the Smart Forest

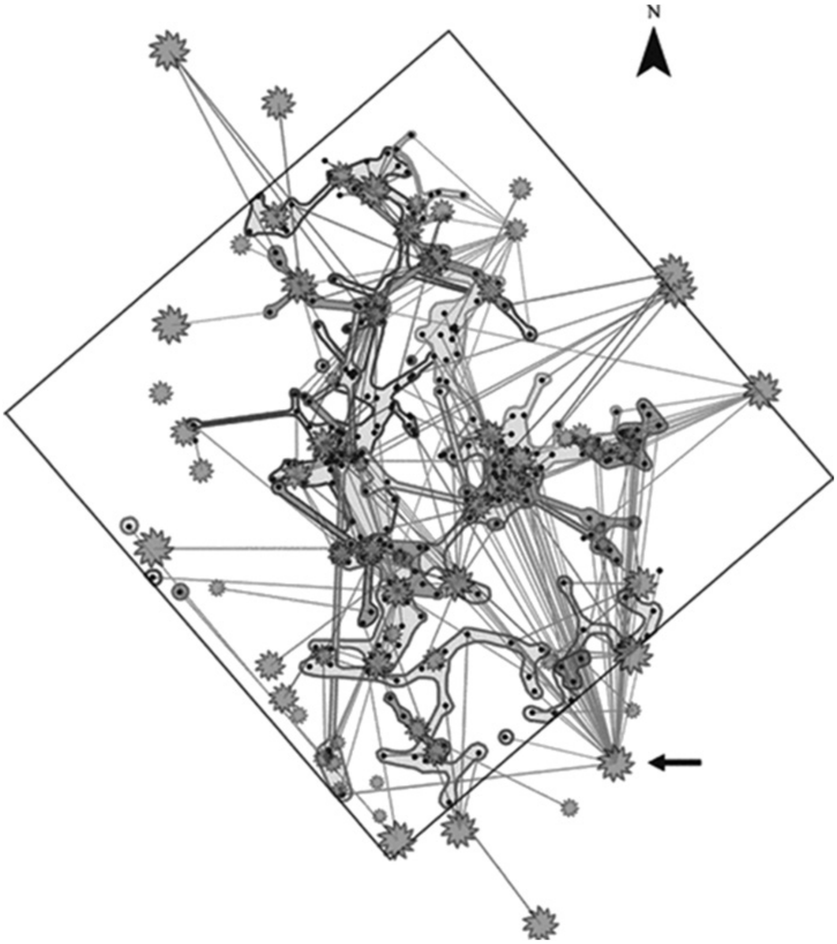
In ecology, too, resilience is now a contested concept and tool for reimagining more diverse futures and forms of life. Suzanne Simard, a forestry professor at the University of British Columbia, is a leading voice in contemporary forest management and is best known for her work on forests as communication systems that have "social lives."[79] In the late 1980s and 1990s, Simard (like Holling a few decades earlier) worked for the Canadian forestry industry. Her studies demonstrated, again, that when loggers replaced diverse forests with homogeneous plantations the new trees failed to thrive. However, Simard, perhaps unintuitively, noted that part of this plantation system required the clearing of underbrush and the movement of soil, so she began to examine the soil. Her article and thesis in the mid-1990s on the subject changed the field significantly.[80]

Simard discovered that trees communicate through networks of mycorrhizas that exchange carbon, phosphates, and hormones. She subsequently employed genomics, radiation sensing, and a combination of big data from satellite, forest sensing, and genomic testing to illuminate the incredible complexity of biodiversity and its importance for conservation. A central component of her approach was the idea of a "mother tree": a living archive of both knowledge and energy for the forest. These trees foster seedlings and are critical nodes that permit the forest to thrive. Advanced mapping of this network—which was, in essence, a smart or big-data project, though for unusual ends—facilitated an understanding of the key infrastructures that, if destroyed, lead rapidly to the demise of the entire ecosystem.[81]

The work of Simard and fellow ecologists creates a different visualization of the forest (see figures 4.13 and 4.14). Major news outlets translated this



4.13 Network image showing the linkages between Douglas fir trees through the mycorrhizal network. The arrow points to the most highly connected tree. *Source*: Beiler et al. 2010, displayed online in Suzanne W. Simard, "Nature's Internet: How Trees Talk to Each Other in a Healthy Forest," TEDxSeattle, February 2, 2017, https://www.youtube.com/watch?v=breDQqrkikM.



4.14 Another network image of tree exchange of nutrients. “Woodwide webs” showing links between older “mother” trees, saplings, and other species of trees. The lines illustrate the flow of chemicals and energy between the trees. The studies even demonstrated that trees can signal each other to begin preparing against predators, such as budworms. This incites the surrounding trees to begin preparing defenses (sap) against possible insect invasion. *Source*: Suzanne W. Simard, “Nature’s Internet: How Trees Talk to Each Other in a Healthy Forest,” TEDxSeattle, February 2, 2017, https://www.youtube.com/watch?v=breDQqrkikM.

Excursus 4.2 (continued)

data and approach into the claim that forests have a "social life," that trees "communicate" with each other, and that we should never "underestimate the intelligence of trees."[82] Simard herself, however, discusses the forest in terms of smartness and calls a forest "an internet of trees"; in this way, she clearly asks her audiences to understand a forest in terms of the communication networks usually assigned to digital media. And for Simard this is not simply a metaphor, for her modes of visualization—from Geiger counters and tracing the spread of radiation among mycorrhizal networks and through root systems and soil to genomic analysis—are all forms of digital visualization that became possible in the past recent decades and facilitated the production of models that could not be seen earlier (and hence could not be imagined).

Simard cites Gunderson and Holling as her predecessors and extends their understanding of biodiversity into adaptation. As she and her colleagues write in a recent summary article, they understand adaptation to be the next step in understanding ecosystems:

> The adaptive capacity of many complex systems is related to the concept of ecosystem resilience [developed by Holling and Gunderson] but with an important difference. Ecological resilience can be characterized by the amount of change that an ecosystem can absorb before it loses its ability to maintain its original function and structure, i.e., its identity. Following a disturbance, a resilient system has the potential to recover its original structure, functions and feedbacks. In contrast, adaptation enables an ecosystem to modify its structure and composition so it can sustain major functions or develop new ones. It enables the ecosystem to reorganize in a manner that avoids maladaptation to the new environmental conditions.[83]

Within the new matrix of ecology governed by means of complexity theory, true resilience is no longer simply sustainability but adaptability. This is a form of adaptability, moreover, that only comes to be through networks of smartness—that is, codependencies and relations between many parts of the forest and diversity in the underbrush, in the trees, and in the soil.

Mycorrhizal networks are essential for this approach, for they share chemical signals, nutrients, and carbon among the trees. These forms of communication, sharing, and signaling play critical roles in adaptation. These networks, ecologists argue, are not only information systems like markets, signaling different life forms to adapt. The networked forest, ecologists argue, also has a *memory*:

> Complex systems accumulate information from the past that influences future trajectories through persistent change in the system's structure and composition. . . . This *memory* may derive from past events, some minor or random, that are reinforced through feedbacks in the system and constrain its future trajectory. In forests, early recruitment of pioneer species following a disturbance modifies the habitat and influences prospective colonists. . . . Forest management practices may also create path dependency, as for example in Canada, where an emphasis on stand-level silvicultural planning still drives current management practices. This emphasis persists despite new technologies (such as GIS and GPS) that readily permit management at larger scales that may be more ecologically and economically relevant.[84]

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Excursus 4.2 (continued)

Forests have memories, and these memories shape the future of the ecosystem. These memories are held within the material bodies of the plants and related species, as well as in the choices made by humans and by the vagaries of which trees are grown and where. For Simard, the forest's ability to communicate, the strength and vitality of the nodes of mother trees, and the trees' connection to other species and their saplings are all questions of history. A system that has been devastated and monocropped will lack the material memory to adapt to future changes.

This memory augments the machine systems that both make this forest visible and enable it to be destroyed. The proto–geographic information and proto–global positioning systems that Holling first used in Canada allow for ongoing understanding of the changing densities, species, and temperatures of the forest. However, this knowledge must be used within the context of understanding the system as changing and always evolving, rather than as static.

This understanding of the forest and how one can maintain its "services" has been critical to changing the practices of forest management. This underscores the more general point that specific ways of visualizing life have material impacts on that life itself. Simard and her colleagues argue that good policies encourage forest harvesting that respects the network and avoids damaging critical nodes. They also argue that wood *can* be harvested, but only if care is taken not to clear cut and attention is paid to regrowing the forest undergrowth, maintaining the soil's diverse life forms, and reintroducing multiple tree species on the basis of an understanding of their interrelationships.

We have highlighted this new understanding of adaptability because it also highlights the positive potential of the concept of resilience. In this case, new forms of digital data and imaging, combined with new models of networks, learning, adaptation, and communication, have led to forms of managing forest futures in more diverse ways. Complexity systems thinking in forestry understands the need for change and understands that forests are always in transition while also emphasizing "holistic" management approaches, which (to paraphrase Holling) enhance adaptability and resilience for futures that cannot be fully predicted. Diversity is a value in part because of uncertainty.

CONCLUSION

At stake in the competing understandings of resilience and antifragility that we have noted above is the common question of what, precisely, "learning with continuity," to draw on Holling's powerful phrase, can and should mean and how computation fits into that aspiration. We can parse this into four questions: What is *learning*? What must *remain continuous* for learning to happen? What is the role of computation in learning with continuity? And on what *image of biological evolution* does such learning model itself?

We take up the second question first, for the question of what must *remain continuous* for learning to happen provides the clearest axis of distinction among the different images of resilience and antifragility that we have discussed in this chapter. BCM stands at one extreme. This practice focuses solely on the individual corporation and seeks to ensure that the core business—and ultimately the elements of the core business that affect the corporation's share price or profit margin—remains continuous. The environment of the business, whether understood as the natural, political, or social environment, is relevant only insofar as it bears upon the ability of the legal entity of the corporation to persist through time. In practice this means that the resilience at which BCM aims requires the persistence of the legal, political, and social status quo. The problem with that approach to resilience, Keeling suggests, is that it forecloses on a future not predicated upon racial capitalism. Drawing on the example of Royal Dutch Shell—the company that, as we noted above, was central to the development of scenario planning as a corporate practice—Keeling contends:

> Royal Dutch Shell's existence is predicated on a system of racial capitalism that thrives on the dispossession and exploitation of Black people, Indigenous peoples (some of whom describe themselves as "Black"), and people of color. A future in which Royal Dutch Shell would continue to exist as such forecloses upon a future in which those groups of living beings we currently can identify as "Black people" and/or Indigenous peoples, have the resources to enjoy a sustainable and joyful existence on this planet.[85]

For Keeling, the learning that is necessary in order to create a future that is *not* simply an extension of the inequities of the present can be found in the continuous and resilient "freedom dreams" of what Cedric J. Robinson first called the Black radical tradition, which has thrived not simply in the face of, but because of, the shocks and trauma that partly engendered it.[86] Where corporate, financial, and logistical approaches to resilience assume a world of scenario plans and unanticipatable futures divorced from historical legacy or context—and where focusing on services eliminates any need to consider the specifics of environments or milieus—Keeling understands resilience as inextricably linked to an extended historical consciousness and to the conscious and planned redesigning of institutions and environments.

Keeling's stress on the link between resilience and an extended historical consciousness seems to us well worth endorsing. This link underscores the extent to which Hayek's image of the market as information processor—and, to a lesser extent, Holling's image of ecosystem services that persist even as individual species come and go—has no interest in history: so long as the market (Hayek) or ecosystem services (Holling) persist, the species of the past are of no interest or relevance. Hayek's and (sometimes) Holling's disinterest in history is drawn from their understanding of evolutionary biology, for whatever evolutionary links there might be between a species in the present and the ancient species to which it is related is of no interest or help to the present species in its struggle for survival.

This in turn highlights the difficulties of drawing on biological evolution as a model of *learning*. While biological speciation certainly involves *change*, it is hard to see what, precisely, *learns* as a consequence of that change (if only because no species gets a chance to learn from its mistakes after it has gone extinct). Keeling's approach thus suggests that understanding resilience as a call for multiplicity, and for futures not yet known, will require a mode of ecological thinking that runs counter to the optimizing demands of capital and that can offer the possibility not of a new normal but a new nature.

At the same time, we also need to rethink the role of computation and sensing (and the infrastructures and institutions that support these functions) in enabling this new ecology of learning. Computation, in Keeling's account, seems to be primarily a support of racial capitalism, and it is possible to imagine, following Fred Moten, that in the face of the smartness mandate or any other aspect of the normative present "the only thing we can do is tear this shit down completely and build something new."[87] If we return to our example of the COVID-19 pandemic, though, it is not entirely clear what this means or how it would differ from the current strategy of the political Right. Presumably, it *is* a good thing to track and seek to control COVID-19 curve rates via smart technologies, to analyze this data carefully to determine which communities are suffering disproportionately and to seek to ameliorate those differences, and to provide intensive care to anyone who needs it. The alternative strategy favored by the Right—namely, actively dismantling the systems that would allow for this kind of tracking and care—in the end amounts to a sort of economically oriented triage logic, according to which those who have the economic means ensure care for themselves, and everyone else is forced to hope for the best.

The strategy of tearing everything down also arguably overestimates the coherence of "the system" and so misses chances for both learning and continuity. The genealogical approach that we take in this book is intended to underscore the (generally unintentional) bricolage that has brought together the premises, technologies, and *dispositifs* of the smartness mandate. This bricolage in turn means that these networked computational technologies can be used to other ends. One starting point, for example, would be to identify those services—for example, equitable health care or universal food and emotional support during a global pandemic—that we wish to remain continuous and to figure out concretely the ways in which the tools of smartness can be reoriented toward those goals. In Simard's new ecology of the smart forest, we can perhaps see at least an inkling of what such a rethinking might mean. And in our coda, we will turn to what it might mean to explore the layered temporalities and bricolages of smartness.

CODA: FROM THE SMARTNESS MANDATE TO THE BIOPOLITICAL LEARNING CONSENSUS

The smartness mandate is the demand, cast by its advocates as having the force and irresistibility of a law of nature, that all social processes become smart. A social process becomes smart when the populations within which that process occurs are redesigned as experimental zones, so that widely distributed forms of electronic sensing produce data that can be processed algorithmically, and in this way enable constant and quasi-automatic learning about, and adaptation to, an ever-changing environment (i.e., resilience). Because smartness is presented as a—or more often, the only—means by which humans can successfully adapt their current highly technical collective existence to those threatening changes in global ecology and geology that humans themselves have engendered, the smartness mandate seems to emanate less from sites and structures of human government than from nature itself and its evolutionary processes.

As we have documented in this book, many of the guiding premises and models for the smartness mandate first emerged in what we might broadly call the cybernetic sciences of the 1940s and 1950s. These elements were linked to one another in new ways in the 1970s and 1980s, often as responses to new forms of global relations, including postcolonial movements (which called into question the post–World War II geopolitical order), changes in the structure of global monetary flows and finance (the collapse of the Bretton Woods international currency system enabled, for example, a new system of finance and derivatives), and ecological concerns (which stressed for many the inability of the traditional nation-state to address problems that extended beyond national territories). These new linkages solidified into the smartness mandate in the early 2000s, often guided by the convergence of neoliberal policies and the new capacities of computing and sensing technologies.

Yet we have also stressed in each chapter both the contingent nature of these connections and the alternative possibilities enabled by the premises, models, and techniques that make up the smartness mandate. In our coda we expand on these alternative possibilities, and we do so in the name of what we will call the *biopolitical learning consensus*. The smartness mandate seems to be a mandate in part because of the high stakes involved: for its advocates, we *must* become smart or else go extinct as a species. And the smartness mandate enjoins us to smartness—rather than, for example, rationality—in order to underscore the inability of unassisted human reason to understand and cope with the modern challenges that humans face; as a consequence of this incapacity, humans need learning processes that take place largely within computer systems and that have no telos other than perpetual resilience.

What we call the biopolitical learning consensus agrees that unassisted human reason cannot fully understand and cope with the modern challenges that humans face and that, as a consequence, humans need learning processes that take place at least partly within computer systems. Yet for the biopolitical learning consensus, the limits on unassisted human reason stem less from intrinsic limits of rationality than from the fact that there is no one group of humans that would ever be able to define the nature and contents of rationality or human reason. Rationality is *not* something that can be defined and axiomatized by, for example, the game theorists of the 1960s; rather, it is a capacity that is always at work and that works differently in every human collective. Learning processes that take place in part within computer systems thus need to remain open to different perspectives on both what constitutes rationality and what counts as learning.

In place of a *mandate* to be smart, the biopolitical learning *consensus* seeks to bring these different perspectives together—that is, to feel and think together with them. And unlike past examples of political "consensus" that in fact represented agreement among a very small number of people—for example, the neoliberal "Washington Consensus" that emerged in the late 1980s—this consensus has no geographic location but rather comes together through the distributed efforts of those interested in learning in all its forms.

The linkage we make between learning and plurality seeks, in one sense, to lead the thought of populations away from their conceptual and literal capture by markets. In chapter 1 we presented biologist Ernst Mayr and economist Friedrich Hayek as uncanny doubles of one another. Neither was interested in equilibrium states but rather in what happened when conditions *changed*. Both felt that differences between each of the members of large collectives—biological populations, for Mayr; market participants, for Hayek—were key to understanding both the capacity for, and the actual process of, adaptation to a changing environment. For both Mayr and Hayek, this process of adaptation was invisible to the participants within this process: a subspecies adapts to its changing environment by transforming into a new species, but no member of the species can be said to learn in this process. In similar fashion, the market "processes" the local information possessed by each market participant by means of the prices of goods, but neither the market as a whole nor any market participant learns, precisely. Yet, perhaps paradoxically, the points of conceptual resonance between Mayr's and Hayek's accounts enabled concepts from each of their respective disciplines to serve, beginning in the 1950s, as points of orientation for computer models of *human* learning and, subsequently, for models of *computer* learning.

For the biopolitical learning consensus, the concept of population is much more helpful than the concept of the market for reappropriating concepts of learning. This is in part because, even in Mayr's biological formulation, population has a much more capacious sense of difference than does Hayek's market. While Hayek's market participant is, like Mayr's biological individual, a site of difference, Hayek's market eliminates any difference that cannot be related to the market metric of price. While fitness might seem to play the same role in Mayr's account, in fact the persisting ambiguities of what, exactly, constitutes biological fitness necessarily make this a more capacious concept. However, beyond this narrow biological point, population is also a term employed within numerous discourses, including demography, public health, and public policy, which opens up this concept toward what Roberto Esposito and others have described as an *affirmative* biopolitics.

In each chapter we have sought to illuminate contemporary experiments that direct collective intelligence, sensing, computation, ecology, and economy toward more equitable shores—that is, toward what we are calling the biopolitical learning consensus. As a way of illuminating the latter even further, we close with some final reflections under two headings: the relationship of learning to democracy and the relationship of learning to history and memory.

LEARNING AND DEMOCRACY

Smartness is understood by its advocates as a method of perpetual learning. For this reason it is fundamentally distinguished from rationality, which in all of its modalities (ancient, classical, Cold War, and so on) focuses on stable criteria for judgments. Smart technologies are perpetually involved, of course, in making judgments. However, these judgments are understood as always provisional and error prone and hence primarily occasions for further learning. Moreover, both these provisional judgments and the open-ended process of learning that they enable cannot be restricted to the conscious decisions of humans because they also involve *automated* judgments based on large data sets and environmental systems of sensing. And because smartness presumes an environment that can never be fully known or mapped, learning has no endpoint: that is, there can be no state of knowledge or decision-making beyond smartness.

This approach to judgment and learning sets up a potential conflict with the values and procedures of democracy, though this differs in important ways from the tension between democracy and neoliberalism. As historians of economics such as Philip Mirowski and Edward Nik-Khah have documented, neoliberal economists—who often also served as shock doctrine consultants—made no secret of their disdain for democracy whenever the latter seemed to question the purported wisdom enabled by markets.[1] For neoliberal economists such as Friedrich Hayek, George Stigler, and Milton Friedman, the process of voting that occurs within a representative democracy is a coarse and problematic approximation to the distributed decision-making that occurs through purchasing decisions; ideally, then, the decisions currently made by means of democratic political processes would be shifted into purchasing decisions.[2]

On the one hand, smartness is also characterized by an elective affinity to markets, since the latter employ a quantitative measure (price) that can easily be integrated into smart learning algorithms for the purpose of "weighting" elements of the latter. On the other hand, smartness is *not* committed to price as the measure of all things, for the "wisdom" of its distributed populations can also employ nonprice metrics (e.g., page-ranking methods, Wikipedia, etc.). Yet because its distributed knowledge can *only* be harnessed by means of environmental sensing and algorithmic computation, smartness still bears a fundamentally ambivalent relationship to democracy, since it is not clear what role machines and automated modes of decision-making ought to play in democratic processes.

We wonder whether democracy and smartness might be brought closer together by thinking about the latter through the example of one of the supposed detriments of liberal democracy—namely, its tendency toward perpetual conversation. Twentieth-century critics of democracy such as Carl Schmitt and Leo Strauss pointed to what they saw as a contradiction between the democratic assumption that the diverse perspectives of the populace must be respected in any concrete decision and the fact that every concrete decision necessarily negated the validity of the perspectives of those who voted against the decision.[3] For Schmitt and Strauss, this meant that democracy was either a perpetual conversation that avoided ever arriving at concrete decisions or that it must make recourse to extrademocratic states of exception in order to make concrete decisions. Yet the temporal orientation of smart learning—its open-ended commitment to revision and change—might itself serve as a figure for the open-endedness of democracy, in the sense that smartness necessarily involves decisions but does not necessarily consider any of those final. From this perspective, the fact that the quantitative dimension of smartness is not bound to the market (even if it often finds itself drawn into the gravity of the latter) certainly makes it a better bedfellow for democracy than neoliberalism proper, for the latter precludes any court of appeal beyond the market's red tooth and claws. (Nor, we will add, are the aspirations of contemporary democracy necessarily alien to big data and algorithms, for it was precisely the latter that enabled critics of gerrymandering to prove to the US Supreme Court that such had in fact taken place in North Carolina in the United States.[4])

The question of what learning means is clearly key to any effort to bring smartness and democracy closer to one another. If smart learning is understood through a Darwinian image of winners ruthlessly culled from losers in a process of evolution, smartness will likely always find itself unable to escape the event horizon of the market. We have pointed, however, to other images of natural evolution—for example, the smart forest—that can move us toward other images of learning. Nor does learning itself need to be bound to a biological image. To return to our opening example of the Event Horizon Telescope, we find hope in the signals of a black hole, which were sent eons ago from a time beyond human—even Terran—time. This is a reminder that some experiences can only emerge through the global networks of sensory and measuring instrumentation. There are in this sense radical possibilities in realizing that learning and experience might be not only internal to subjects but also shared. Perhaps these are just realizations of what we have known all along: that our worlds are composed of relationships to Others.

HISTORY AND MEMORY

As we have noted at multiple points in this book, the "success" of smartness is in large part a function of its agnostic relationship to crisis and catastrophes. Rather than seeking to specify in advance what might constitute a crisis—a specification that would itself require explicit value judgments—smartness instead presents itself as an all-purpose method for responding to any and all crises, whether these seem primarily political (e.g., terrorism), economic (e.g., collapse of futures markets), medical (e.g., pandemics), or ecological (e.g., rising sea levels). Smartness is both an epistemology and a set of technologies for ensuring consistency throughout multiple crises, or what Holling called "learning with continuity." Though smartness has a memory of sorts, in the sense that each crisis should be an occasion to learn even more about the means for ensuring consistency in the next crisis, there is no space in the epistemology of smartness for history, memory, and historical trauma in the sense in which we usually understand those terms.

We have thus sought, at various points, to open up smartness to traditional understandings of history, memory, and historical trauma. In some cases this was via an appeal to alternate understandings of natural evolution: for example, Simard's understanding of the smartness of forests as in part a function of their capacity for extended memory. In other cases we emphasized the long lineages of trauma of those deemed "losers" by a market-oriented vision of smartness (for example, those who lost houses in the global market crash of 2008, who were overwhelmingly also those who would earlier have been denied housing loans due to racial redlining policies). In addition, we excavated alternative visions of computation and living, such as the Japanese architect Arata Isozaki's City in the Air project, which was like, yet differed significantly from, Negroponte's vision of soft architecture. Had these past experiments been embraced, they would have led smartness in different directions. They are in this sense especially important to our project, for they underscore that the smartness mandate was not inevitable but instead resulted from contingent connections and alliances.

To stress even further this fact of contingency, we wish to recall that although machine learning since the 1950s has become a project of revising cognition, it was originally an attempt to understand better what we might call the historical dimension of human perception. The first model of a neural network, for example—Frank Rosenblatt's perceptron—was not introduced as a model of artificial intelligence but was intended to teach us about natural intelligence. The perceptron was not a technical solution to a problem (how to automate pattern recognition) but rather a way to pose questions and learn about an unknown entity (natural intelligence). Or, more accurately, it was an experimental construct for producing models, which asked: How might such a model change how we understand what a machine or a mind *might* be?[5]

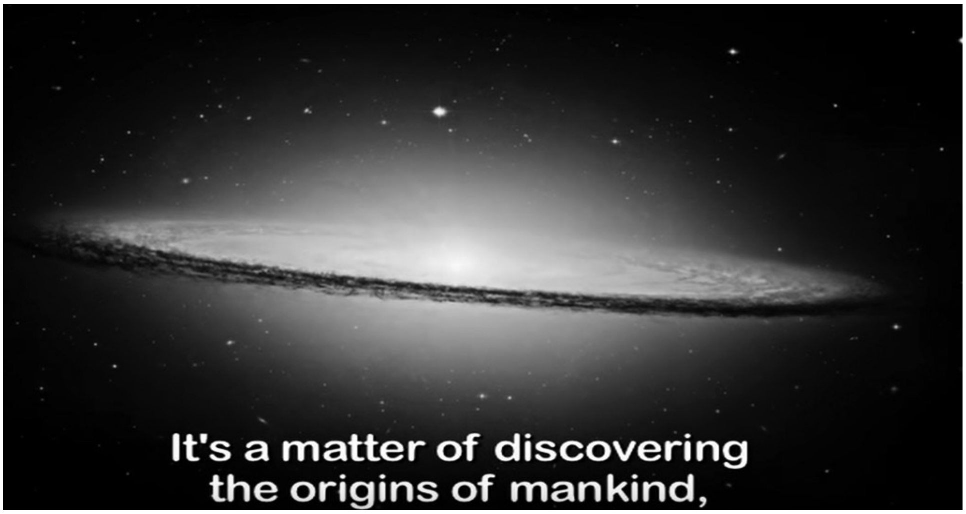
One answer to that question emerged from the genealogical relationships among Rosenblatt, Hayek, and Hebbs (as well as Donald Ewen Cameron, Milton Friedman, Augusto Pinochet, and a host of others) and eventually gave rise to what Naomi Klein called the shock doctrine. Yet the movement from the shock doctrine to the smartness mandate reveals yet a different answer, or set of answers, to the question of what machines and minds—and their interrelationships—might be. Our hope, of course, is that this book can, by returning us to this contingent genealogy, help us to formulate yet other answers.

We conclude by returning to the beginning. The Atacama Desert, where we began our prologue, is, on the one hand, the site of new capacities: a site, for example, in which astrobiologists can locate new forms and modes of life; a site for which computer scientists can develop new mathematics of real-time monitoring and modeling of massive copper and gold mines; and a site by means of which astronomers can produce new images of aspects of the universe, such as the event horizon of a black hole. On the other hand, the production of these new capacities in the Atacama also seems to bring its own forms of death by contributing, for example, to the disappearance of native flora and fauna, including Indigenous human groups. But even in the face of this apparent loss and death, smartness is positioned by its advocates as a potential savior. Sociedad Química y Minera engineers, for example, assert that new technologies will allow water managers to optimize water usage by recycling and collecting the water that evaporates. Smartness purportedly enables, in other words, the *most* finite resource in the desert (water) to become elastic and optimizable and allows the environment more generally to become fortified and made resilient. From this perspective, resource limitations and catastrophic environmental events no longer emerge as "crises" that necessitate responses by experts (even those economists who are experts in "austerity" fiscal policies). They can instead be addressed through incremental experiments, which enable would-be crises to be ameliorated through endless adjustments and manipulations of time and data collection.

Yet time and data can be manipulated in many ways, and one specific manipulation of this same desert—Patricio Guzman's film *Waiting for the Light* (2010)—underscores some of what is lost in these dreams of smartness. In the immediate aftermath of the September 11, 1973, coup in Chile, nearly 10 percent of the national population was tortured, "disappeared," or exiled. Some of those who were disappeared ended up in the desert, first taken by Puma helicopter from detention sites and then either killed and buried in unmarked graves or thrown from the helicopter. These disappearances were only a small part of a larger program of torture and murder. Over 2,000 Chileans were murdered, and tens of thousands tortured. Thousands also fled the country (see figure C.1).[6]

C.1 Calama Memorial for the Pinochet victims. *Source*: Wikimedia Commons, accessed August 6, 2019, https://commons.wikimedia.org/wiki/File:Memorial_DDHH_Chile_06_Memorial_en_Calama.jpg.

Guzman's film creates visual parallels between, on the one hand, the search by mothers for the bodies of their children killed by Pinochet's supporters and, on the other, astronomers watching and recording the stars in the Atacama's high-altitude observatories. (The wave millimeter arrays were not yet functioning when Guzman created his film). Guzman treats the desert landscape as a recording machine for both human and inhuman memories: the search for murdered loved ones and the trace of stars 50 million light-years away. The film thus suggests that the desert provides some kind of intelligence and memory that is partially accessible, but not restricted, to humans. Guzman offers us a dangerous romance with the possibilities afforded by our nonhuman intelligences that augment or supplant our human memories (see figures C.2 and C.3).



C.2 Patricio Guzman, *Waiting for the Light*, 2010.

C.3 Patricio Guzman, *Waiting for the Light*, 2010.

His story ties together tales of cybernetics, astronomy, and economy in a way that confronts both the horror of and our capacity to imagine encounters with radical forms of difference. In many ways it refracts the event horizon as an image. It is the image of what we cannot see. It is proof of the limits of scientific representation. Our hope is that by reflexively encountering through our machines the very limits to human knowledge and control, we might envision another path for smartness—a path that, by recognizing the limits to computation, realizes new possible relations of care and participation to the world.

NOTES

PROLOGUE

1. Wikipedia, s.v. “event horizon,” last modified January 29, 2022, https://en.wikipedia.org/wiki/Event_horizon.

2. Dennis Overbye, “Darkness Visible, Finally: Astronomers Capture First Ever Image of a Black Hole,” *New York Times*, April 10, 2019, https://www.nytimes.com/2019/04/10/science/black-hole-picture.html.

3. Another technique employed here is to cool units at the base of the telescopes to the temperature of deep space in an effort to isolate and process signals from space and separate them from “noise” from the earthly atmosphere. By returning the signal to its original temperature, the appropriate wavelengths of the signals can be isolated. In this installation, then, data is literally being contextualized in an environment that is built within the experimental setup, in the sense that the stellar “outside” of the earth is recreated within the machines. This was explained to Orit Halpern by an on-site technician on March 13, 2021.

4. Martîn Arboleda, *Planetary Mine: Territories of Extraction under Late Capitalism* (New York: Verso, 2020), 66.

5. Staff reporter, “Codelco to Deploy AI Solution,” *Mining Journal*, March 26, 2019, https://www.mining-journal.com/innovation/news/1359598/codelco-to-deploy-ai-solution.

6. Lithium was first discovered in 1817 by Swedish chemist Johan August Arfwedson. Arfwedson, however, was not able to isolate the metal when he realized that petalite contained an unknown element. In 1855, British chemist Augustus Matthiessen and German chemist Robert Bunsen were successful in separating it. It is one of the lightest and softest metals. In fact, it can be cut with a knife. And because of its low

density, lithium can even float in water. Terence Bell, "An Overview of Commercial Lithium Production," Thought Co., last modified August 21, 2020, https://www.thoughtco.com/lithium-production-2340123; "Lithium," Royal Society of Chemistry Periodic Table, accessed March 15, 2021, https://www.rsc.org/periodic-table/element/3/lithium.

7. Alejandro Bucher (technical manager, SQM), interview by Orit Halpern, March 23, 2017. See also Paul Harris, "Chile Seawater Desalination to Grow 156%," *Mining Journal*, January 27, 2020, https://www.mining-journal.com/copper-news/news/1379729/chile-seawater-desalination-to-grow-156; Rebecca Boyle, "The Search for Alien Life Begins in Earth's Oldest Desert," *Atlantic*, November 28, 2018, https://www.theatlantic.com/science/archive/2018/11/searching-life-martian-landscape/576628/.

8. Michelle Carrere, "Chile Renews Contract with Lithium Company Criticized for Damaging Wetland," trans. Sydney Sims, *Mongabay*, December 16, 2018, https://news.mongabay.com/2018/12/chile-renews-contract-with-lithium-company-criticized-for-damaging-wetland/.

9. Lorena Gúzman, "The Fight for the Control of Chile's Lithium Business," *Diálogo Chino*, December 7, 2018, https://dialogochino.net/15614-the-fight-for-control-of-chiles-lithium-business/.

10. Carrere, "Chile Renews Contract."

11. Frank Tavares, ed., "Cooking Up the World's Driest Desert—Atacama Rover Astrobiology Drilling Studies," NASA, June 20, 2018, https://www.nasa.gov/image-feature/ames/cooking-up-the-world-s-driest-desert-atacama-rover-astrobiology-drilling-studies.

INTRODUCTION

1. Sam Palmisano, "A Smarter Planet: The Next Leadership Agenda," Council on Foreign Relations, November 6, 2008, https://www.youtube.com/watch?v=i_j4-Fm_Svs.

2. Palmisano, "A Smarter Planet."

3. Tom Warren, "Microsoft Teams Jumps 70 Percent to 75 Million Daily Active Users," *The Verge*, April 29, 2020, https://www.theverge.com/2020/4/29/21241972/microsoft-teams-75-million-daily-active-users-stats.

4. Paul Erickson, Judy L. Klein, Lorraine Daston, Rebecca M. Lemov, Thomas Sturm, and Michael D. Gordi, *How Reason Almost Lost Its Mind: The Strange Career of Cold War Rationality* (Chicago: University of Chicago Press, 2015), 2. Erickson and his coauthors stress that for Cold War authors and policy-makers, the possibility of nuclear war made it imperative that people—or at least military commanders and policy-makers—act "rationally," in the sense that tendencies to innovate or depart from programmable rules be prevented; the consequence was that "mechanical rule following . . . become the core of rationality" (31).

5. Though the image of Cold War rationality developed by Erikson et al. is especially useful for our purposes here, we also want to acknowledge alternative histories of temporality and control, many emerging from cybernetics, within the history of

Cold War computing. See, e.g., Orit Halpern, "Cybernetic Rationality," *Distinktion: Scandinavian Journal of Social Theory* 15, no. 2 (2014): 223–238.

6. Naomi Klein, *The Shock Doctrine: The Rise of Disaster Capitalism* (New York: Metropolitan Books/Henry Holt, 2007). Klein's book is part of an extensive bibliography of recent critical work on neoliberalism that also includes David Harvey, *A Brief History of Neoliberalism* (New York: Oxford University Press, 2005); Philip Mirowski and Dieter Plehwe, eds., *The Road from Mont Pèlerin: The Making of the Neoliberal Thought Collective* (Cambridge, MA: Harvard University Press, 2009); Jamie Peck, *Constructions of Neoliberal Reason* (New York: Oxford University Press, 2010); and Philip Mirowski, *Never Let a Serious Crisis Go to Waste: How Neoliberalism Survived the Financial Meltdown* (New York: Verso, 2014).

7. See especially Michel Foucault, *The History of Sexuality*, vol. 1, *An Introduction*, trans. Robert Hurley (New York: Pantheon Books, 1978); Foucault, *Society Must Be Defended: Lectures at the Collège de France, 1975–76*, ed. Mauro Bertani and Alessandro Fontana, trans. D. Macey (New York: Picador, 2003); Foucault, *Security, Territory, Population: Lectures at the Collège de France, 1977–78*, ed. M. Senellart, trans. G. Burchell (New York: Palgrave Macmillan, 2007); and Foucault, *The Birth of Biopolitics: Lectures at the Collège de France, 1978–79*, ed. M. Senellart, trans. G. Burchell (New York: Palgrave Macmillan, 2008); Gilles Deleuze, "Postscript on the Societies of Control," *October* 59 (1992): 3–7; and reflections on immaterial labor in Maurizio Lazzarato, "Immaterial Labor," in *Radical Thought in Italy*, ed. Paolo Virno and Michael Hardt (Minneapolis: University of Minnesota Press, 1996), 132–146; and Michael Hardt and Antonio Negri, *Empire* (Cambridge, MA: Harvard University Press, 2000), 290–294.

8. For a key early reflection on biological "population thinking," see Ernst Mayr, "Darwin and the Evolutionary Theory in Biology," in *Evolution and Anthropology: A Centennial Appraisal*, ed. B. J. Meggers (Washington, DC: Anthropological Society of Washington, 1959), 1–10. For a helpful reflection on key aspects of biological concepts of population, see Peter Godfrey-Smith, *Darwinian Populations and Natural Selection* (Oxford: Oxford University Press, 2009).

9. On complicated and shifting relationships between natural and social scientific approaches to population in the twentieth century, see Edmund Ramsden, "Eugenics from the New Deal to the Great Society: Genetics, Demography and Population Quality," *Studies in History and Philosophy of Biological and Biomedical Sciences* 9 (2008): 391–406.

10. See "Recommending for the World," *Netflix Technology Blog*, accessed October 27, 2016, https://netflixtechblog.com/recommending-for-the-world-8da8cbcf051b.

11. As these examples suggest, we see the concept of population as more useful for an analysis and critique of smartness than contemporary alternatives such as crowds, swarms, and collectives. While each of these terms admittedly stresses different aspects—population emphasizes long-term biological adaptability and persistence, crowds and swarms emphasize speed of change and decentralized control, and collective is clearly a more political term—the concept of population underscores the evolutionary logic of smartness, as well as the underlining meanings of optimization

and resilience central to its operation. The concept of "multitude" employed (in different ways) by Paolo Virno and by Hardt and Negri is more helpful in drawing off aspects of smartness from their embeddedness within naturalistic and neoliberal assumptions, yet it is not clear to us that these authors successfully engage the ecological dimension of smartness, which is absolutely essential to its current appeal. See Paolo Virno, *A Grammar of the Multitude: For an Analysis of Contemporary Forms of Life* (New York: Semiotext(e), 2004), and Hardt and Negri, *Empire*, as well as *Multitude: War and Democracy in the Age of Empire* (New York: Penguin Press, 2004), and *Commonwealth* (Cambridge, MA: Belknap Press of Harvard University Press, 2009).

12. See especially Foucault, *The History of Sexuality* 1:25–26, 139–147; *Society Must Be Defended*, 239–264; and *Security, Territory, Population*, 38–44, 62–79.

13. Deleuze, "Postscript on the Societies of Control."

14. On financialization and computation, see Michael Lewis, *Flash Boys: A Wall Street Revolt* (New York: W. W. Norton, 2014), and Donald A. MacKenzie, *An Engine, Not a Camera: How Financial Models Shape Markets* (Cambridge, MA: MIT Press, 2006).

15. On the smart home, see Lynn Spigel, "Designing the Smart House: Posthuman Domesticity and Conspicuous Production," in *Electronic Elsewheres: Media, Technology, and the Experience of Social Space*, ed. Chris Berry, Soyoung Kim, and Lynn Spigel (Minneapolis: University of Minnesota Press, 2009), 55–92.

16. There is considerable work—some very critical and some very utopian—on the "smart" city, smart city projects, and "smart" or big data infrastructures. For a sampling, see Rob Kitchin, *The Data Revolution: Big Data, Open Data, Data Infrastructures and Their Consequences* (London: Sage, 2014); Anthony M. Townsend, *Smart Cities: Big Data, Civic Hackers, and the Quest for a New Utopia* (New York: W. W. Norton, 2014); Carlo Ratti and Matthew Claudel, *The City of Tomorrow: Sensors, Networks, Hackers, and the Future of Urban Life* (New Haven, CT: Yale University Press, 2016); Adam Greenfield, *Against the Smart City (the City Is Here for You to Use)* (New York: Do Projects, 2013); Shannon Mattern, *Deep Mapping the Media City* (Minneapolis: University of Minnesota Press, 2015); and Richard Sennett, "The Stupefying Smart City" (paper presented at the Urban Age Electric City Conference, London School of Economics, December 2012).

17. See Keller Easterling, *Extrastatecraft: The Power of Infrastructure Space* (New York: Verso, 2014); and Ned Rossiter, *Software, Infrastructure, Labor: A Media Theory of Logistical Nightmares* (New York: Routledge, 2016).

18. For more on the "logistical" city and free-trade zones, see Brett Nielsen and Ned Rossiter, "The Logistical City," *Transit Labour: Circuits, Regions, Borders*, no. 3 (August 2011): 2–5; Aiwha Ong, "Introduction: Worlding Cities, or the Art of Being Global," in *Worlding Cities, or the Art of Being Global*, ed. Aiwha Ong and Ananya Roy (London: Routledge, 2011), 1–26; Saskia Sassen, *Expulsions: Brutality and Complexity in the Global Economy* (Cambridge, MA: Harvard University Press, 2014); Manuel Castells, *The Rise of the Network Society* (New York: Wiley-Blackwell, 2000); Deborah Cowen, *The Deadly Life of Logistics: Mapping Violence in Global Trade* (Minneapolis: University of Minnesota, 2014); and David Harvey, *Spaces of Capital* (London: Routledge, 2012).

19. Orit Halpern, Jesse LeCavalier, and Nerea Calvillo, "Test-Bed Urbanism," *Public Culture* 25, no. 2 (March 2013): 274.

20. Smartness thus partakes in what Shannon Mattern calls methodolatry—namely, a constant obsession with methods and measurement to assess prototypes that are never completed; hence, results are assessed without any clear final metric or end point. See Shannon Mattern, "Methodolatry and the Art of Measure," *Places Journal*, November 2013, https://placesjournal.org/article/methodolatry-and-the-art-of-measure/.

21. See, for example, Anson Rabinbach, *The Human Motor: Energy, Fatigue, and the Origins of Modernity* (Berkeley: University of California Press, 1992).

22. We discuss the history of the term "optimization" in chapter 3.

23. Dan Simon, *Evolutionary Optimization Algorithms: Biologically-Inspired and Population-Based Approaches to Computer Intelligence* (Hoboken, NJ: John Wiley and Sons, 2013), 20–21. Marvin Minsky made similar points in his seminal 1960 article "Steps toward Artificial Intelligence," *Proceedings of the IRE* 49, no. 1 (January 1961): 8–30.

24. In the absence of any way to calculate absolute maxima and minima, the belief that smartness nevertheless locates the "best" solutions can be supported technically by running different optimization algorithms on "benchmark" problems—that is, problems that contain numerous local maxima and minima but for which the absolute maximum or minimum *is* known—in order to determine how well a particular algorithm performs on a given kind of problem. If the algorithm runs well on a benchmark problem, then it is presumed likely to run well on similar real-world problems.

25. David B. Fogel, "An Introduction to Simulated Evolutionary Optimization," *IEEE Transactions of Neural Networks* 5, no. 1 (1994): 3. The issue of *IEEE Transactions of Neural Networks* in which this essay appears, titled *Evolutionary Computing: The Fossil Record*, establishes the importance of Mayr's evolutionary population thinking for this approach to computing (e.g., pp. xi, 1, 11, etc.).

26. Louise Amoore, "Data Derivatives: On the Emergence of a Security Risk Calculus for Our Times," *Theory, Culture and Society* 28, no. 6 (2011): 24–43.

27. Stephanie Wakefield and Bruce Braun, "Living Infrastructure, Government, and Destitute Power" (unpublished paper, Anthropology of the Anthropocene, Concordia University, October 23, 2015), 1–24, 7.

28. D. E. Alexander, "Resilience and Disaster Risk Reduction: An Etymological Journey," *Natural Hazards and Earth System Sciences* 13 (2013): 2707–2716. See also Jeremy Walker and Melinda Cooper, "Genealogies of Resilience: From Systems Ecology to the Political Economy of Crisis Adaptation," *Security Dialogue* 2 (2001): 143–160.

29. C. S. Holling, "Resilience and Stability of Ecological Systems," *Annual Review of Ecological Systems* 4 (1973): 1–23, 21.

30. Holling, "Resilience and Stability of Ecological Systems," 21.

31. Resilience is not equivalent to robustness. As Alexander R. Galloway notes in *Protocol: How Control Exists after Decentralization* (Cambridge, MA: MIT Press, 2004), "robustness" is a defining feature of the technical concept of protocol, which is central

to the computational dimension of smart infrastructures (43–46). However, insofar as robustness refers to the ability of a system to retain its original configuration despite confusing input, it is analogous to what Holling called "stability," rather than resilience. Robustness is thus just one of many technical means for enabling resilient systems.

32. Jennifer Gabrys, *Program Earth: Environmental Sensing Technology and the Making of a Computational Planet* (Minneapolis: University of Minnesota Press, 2016), 4; Benjamin Bratton, *The Stack: On Software and Sovereignty* (Cambridge, MA: MIT Press, 2016), 3–5.

33. For literature on resilience in finance and on economic and development policies, see Melinda Cooper, "Turbulent Worlds: Financial Markets and Environmental Crisis," *Theory, Culture and Society* 27, no. 2–3 (2010): 167–190; and Stephanie Wakefield and Bruce Braun, "Governing the Resilient City," *Environment and Planning D: Society and Space* 32, no. 1 (2014): 4–11.

34. Barry Bergdoll, "Introductory Statement," Museum of Modern Art, accessed November 3, 2016, https://www.moma.org/explore/inside_out/rising-currents?x-iframe=true#description; emphasis added. The original website has now disappeared, but similar materials can be accessed at https://www.moma.org/calendar/exhibitions/1028.

35. Frank Knight, *Risk, Uncertainty, and Profit* (Boston: Houghton Mifflin, 1921).

36. As Joseph Vogl notes in "Taming Time: Media of Financialization," *Grey Room* 46 (2012): 72–83, this seems unlikely to be a successful long-term strategy. Yet the logic of the demo fundamental to resilience ensures that even a massive and widespread financial failure, such as the one that began in 2008, can be treated as simply useful material for subsequent versions of the demo; see Mirowski, *Never Let a Serious Crisis Go to Waste*.

37. Among histories of cybernetics, Philip Mirowski's *Machine Dreams: Economics Becomes a Cyborg Science* (Cambridge: Cambridge University Press, 2002) is especially important for us, as Mirowski stresses a connection between cybernetics and economics absent from many other accounts. Our genealogy also draws in multiple places on Lorraine Daston's multiple histories of scientific reason, rationality, and rules, which range from her earlier *Classical Probability in the Enlightenment* (Princeton, NJ: Princeton University Press, 1995) to her more recent work, *How Reason Almost Lost Its Mind*, coauthored with Erickson, Klein, Lemov, Sturm, and Gordin.

38. Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (Cambridge, MA: MIT Press, 2010). Because the smartness mandate is different in kind from climate modeling—the smartness mandate, for example, is not the object of a specific scientific discipline—our method necessarily differs from Edwards. At the same time, his account resonates with ours at multiple points, especially in connection with the ecological concerns and data-gathering techniques that emerged in the 1960s and eventually became part of the smartness mandate.

39. See for example Peder Anker, *Imperial Ecology: Environmental Order in the British Empire, 1895–1945* (Cambridge, MA: Harvard University Press, 2001); Anker, *From*

Bauhaus to Ecohouse: A History of Ecological Design (Baton Rouge: Louisiana State University Press, 2010); and Etienne Benson, *Surroundings: A History of Environments and Environmentalisms* (Chicago: University of Chicago Press, 2020).

40. Fred Turner, *The Democratic Surround: Multimedia and American Liberalism from World War II to the Psychedelic Sixties* (Chicago: University of Chicago Press, 2013).

41. See Yuriko Furuhata, *Climatic Media: Transpacific Experiments in Atmospheric Control* (Durham, NC: Duke University Press, 2022); Nicole Starosielski, *Media Hot and Cold* (Durham, NC: Duke University Press, 2021); Daniel Barber, *Modern Architecture and Climate: Design before Air Conditioning* (Princeton, NJ: Princeton University Press, 2020).

42. Lisa Parks and Caren Kaplan, introduction to *Life in the Age of Drone Warfare*, ed. Lisa Parks and Caren Kaplan (Durham, NC: Duke University Press, 2017), 10.

43. Shannon Mattern, *Code and Clay, Data and Dirt: Five Thousand Years of Urban Media* (Minneapolis: University of Minnesota Press, 2017), xvi.

44. Donella H Meadows, Dennis L. Meadows, Jørgen Randers, and William W. Behrens, *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind* (New York: Universe Books, 1972).

CHAPTER 1

1. Naomi Klein, "Screen New Deal," *The Intercept*, May 8, 2020, https://theintercept.com/2020/05/08/andrew-cuomo-eric-schmidt-coronavirus-tech-shock-doctrine/.

2. For histories of shock as a concept in psychology, see Marc-Antoine Crocq and Louis Crocq, "From Shell Shock and War Neurosis to Posttraumatic Stress Disorder: A History of Psychotraumatology," *Dialogues in Clinical Neuroscience* 2, no. 1 (2000): 47–55; Mark S. Micale and Paul Lerner, eds., *Traumatic Pasts: History, Psychiatry, and Trauma in the Modern Age, 1870–1930* (Cambridge: Cambridge University Press, 2010).

3. Francis Bacon, *The Essays, or Councils, Civil and Moral, of Sir Francis Bacon, Lord Verulam, Viscount St. Alban with a Table of the Colours of Good and Evil, and a Discourse of the Wisdom of the Ancients: To This Edition Is Added the Character of Queen Elizabeth, Never before Printed in English* (London: Printed for H. Herringman, R. Scot, R. Chiswell, A. Swalle, and R. Bentley, 1696), 38.

4. Thomas Malthus, *An Essay on the Principle of Population, as It Affects the Future Improvement of Society. With Remarks on the Speculations of Mr. Godwin, M. Condorcet, and Other Writers* (London: J. Johnson, 1798), 18.

5. Malthus, *An Essay on the Principle of Population*, 14.

6. In later editions of his text, Malthus grudgingly acknowledged, via the introduction of the concept of *moral restraint*, that at least some members of populations could work against these drives. However, he did not see this as a possibility open to enough members of a population to make a difference. On the question of what changes in practice Malthus thought knowledge about population dynamics could produce, see Robert Mitchell, "Regulating Life: Romanticism, Science, and the Liberal Imagination," *European Romantic Review* 29, no. 3 (2018): 275–293.

7. See, for example, Piers J. Hale, *Political Descent: Malthus, Mutualism, and the Politics of Evolution in Victorian England* (Chicago: University of Chicago Press, 2014).

8. On the role of Lotka and Volterra in ecosystem ecology, see Joel B. Hagen, *An Entangled Bank: The Origins of Ecosystem Ecology* (New Brunswick, NJ: Rutgers University Press, 1992), 70–72, 125–136; see also Philip Kreager, "Darwin and Lotka: Two Concepts of Population," *Demographic Research* 21, no. 2 (2009): 469–502.

9. On social Darwinism, see Richard Hofstadter, *Social Darwinism in American Thought* (New York: G. Braziller, 1959); Mike Hawkins, *Social Darwinism in European and American Thought, 1860–1945: Nature as Model and Nature as Threat* (Cambridge: Cambridge University Press, 1997).

10. As Michel Foucault established, this second model of population was essential to the development of biopolitics, which focused on gathering data about population-level norms and regularities with the goal of then altering those norms and regularities. One of Foucault's key examples was eighteenth-century debates about smallpox inoculation, which in some cases involved parsing populations into different groups (for example, based on age) and determining the efficacy of inoculation for each subgroup. See Foucault, *Security, Territory, Population: Lectures at the Collège de France, 1977–78*, ed. Michel Senellart, trans. Graham Burchnell (New York: Palgrave Macmillan, 2007), 55–86.

11. See Lorraine Daston, *Classical Probability in the Enlightenment* (Princeton, NJ: Princeton University Press, 1995).

12. On the rise of probabilistic thinking and techniques in the nineteenth century, see Daston, *Classical Probability in the Enlightenment*; Theodore M. Porter, *The Rise of Statistical Thinking, 1820–1900* (Princeton, NJ: Princeton University Press, 1986); Ian Hacking, *The Taming of Chance* (Cambridge: Cambridge University Press, 1990); Alain Desrosières, *The Politics of Large Numbers: A History of Statistical Reasoning*, trans. Camille Naish (Cambridge, MA: Harvard University Press, 1998). On the development of social insurance structures within the French welfare state, see François Ewald, *The Birth of Solidarity: The History of the French Welfare State* (Durham, NC: Duke University Press, 2020). On the development of workers' compensation in the US, see Paul B. Bellamy, *A History of Workmen's Compensation, 1898–1915: From Courtroom to Boardroom* (New York: Garland Publishing, 1997); John Fabian Witt, *The Accidental Republic: Crippled Workingmen, Destitute Widows, and the Remaking of American Law* (Cambridge, MA: Harvard University Press, 2004). See also Sharon Bertsch McGrayne, *The Theory That Would Not Die: How Bayes' Rule Cracked the Enigma Code, Hunted Down Russian Submarines, and Emerged Triumphant from Two Centuries of Controversy* (New Haven, CT: Yale University Press, 2011), who stresses that in the US the swift passage of workers' compensation legislation and the consequent lack of prior data on which to base insurance premiums encouraged a turn to Bayesian techniques for setting premiums. This is an important point, for it underscores the extent to which actuarial approaches to population also served as vectors for a certain form of mathematical modeling.

13. For an extended discussion of this aspect of biobanks, see Robert Mitchell and Catherine Waldby, "National Biobanks: Clinical Labour, Risk Production, and the

Creation of Biovalue," *Science, Technology, and Human Values* 35, no. 3 (2010): 330–355; and Robert Mitchell, "U.S. Biobanking Strategies and Biomedical Immaterial Labor," *BioSocieties* 7, no. 3 (2012): 224–244.

14. On ways in which research hospital clinics are repurposed to meet research demands, see Mitchell, "U.S. Biobanking Strategies."

15. The concept of *risk factors* emerged in the mid-twentieth century in the context of the population-oriented Framingham Study; see W. G. Rothstein, *Public Health and the Risk Factor: A History of an Uneven Medical Revolution* (Rochester, NY: University of Rochester Press, 2003).

16. As Joseph Dumit documents in *Drugs for Life: How Pharmaceutical Companies Define Our Health* (Durham, NC: Duke University Press, 2012), some physicians hope that eventually all members of the population will take multiple drugs "for life" in order to reduce health risks.

17. Charles Darwin, *The Origin of Species by Means of Natural Selection; or the Preservation of Favoured Races in the Struggle for Life* (London: John Murray, 1859), 5. In *Political Descent*, Hale provides a helpful reading of the role of Malthus in Darwin's theory and the reception of the latter by late nineteenth- and early twentieth-century biological and social theorists.

18. Ernst Mayr, *Systematics and the Origin of Species: From the Viewpoint of a Zoologist* (New York: Columbia University Press, 1942), 5.

19. Mayr, *Systematics and the Origin of Species*, 8.

20. Mayr, *Systematics and the Origin of Species*, 8.

21. Ernst Mayr, "Darwin and the Evolutionary Theory in Biology," in *Evolution and Anthropology: A Centennial Appraisal*, ed. B. J. Meggers (Washington, DC: Anthropological Society of Washington), 2.

22. Mayr, *Systematics and the Origin of Species*, 99.

23. For Mayr's use of Wright's concept of the fitness landscape, see Mayr, *Systematics and the Origin of Species*, 99.

24. In his hugely influential article "Steps toward Artificial Intelligence," *Proceedings of the IRE* 49, no. 1 (1961): 8–30, computer scientist Marvin Minsky discussed both what he called the "hill-climbing" method and problems with that method (9–10) and referred back to both W. R. Ashby and Norbert Wiener's work in the 1940s and 1950s as key theorists for this approach. Minsky's article was one of many in this period—a number of which appeared in various Institute of Radio Engineers (IRE) journals—that provided surveys of what were often called adaptive or self-optimization methods, which mimicked the adjustment and learning capacities of living beings. See, e.g., J. A. Aseltine et al., "A Survey of Adaptive Control Systems," *IRE Transactions on Automatic Control* 6, no. 1 (1958): 102–108. A Google Books search for "phase space" makes clear that both Ashby and Sewall's use of that concept originated in late nineteenth- and early twentieth-century "statistical" (i.e., quantum) physics.

25. For an example of the former, see J. L. Crosby, "Computers in the Study of Evolution," *Science Progress* 55 (1967): 279–292; for an example of the latter, see L. I.

Fogel, A. J. Owens, and M. I. Walsh, "Artificial Intelligence through a Simulation of Evolution," in *Biophysics and Cybernetic Systems: Proceedings of the 2nd Cybernetic Sciences Symposium*, ed. M. Maxfield, A. Callahan, and L. J. Fogel (Washington, DC: Spartan Books, 1965), 131–155, reprinted in Fogel, *Evolutionary Computation*, 230–254. Wright's theory of fitness landscapes has subsequently been extended, primarily through the intermediary of Stuart A. Kaufmann's work, especially *The Origins of Order: Self-Organization and Selection in Evolution* (Oxford: Oxford University Press, 1993) to many other fields, including economics, organization and management sciences, psychology, and political science. For a survey of the influence of the concept of fitness landscapes, see Lasse Gerrits and Peter Marks, "The Evolution of Wright's (1932) Adaptive Field to Contemporary Interpretations and Uses of Fitness Landscapes in the Social Sciences," *Biology and Philosophy* 30 (2015): 459–479.

26. For the context in which Hayek composed and published *The Road to Serfdom*, see Bruce Caldwell, introduction to F. A. Hayek, *The Road to Serfdom: Text and Documents*, ed. Bruce Caldwell (Chicago: University of Chicago Press, 2007), 1–33.

27. On the history of the Mont Pèlerin Society, see Philip Mirowski and Dieter Plehwe, eds., *The Road from Mont Pèlerin: The Making of the Neoliberal Thought Collective* (Cambridge, MA: Harvard University Press, 2009).

28. Friedrich Hayek, "The Use of Knowledge in Society," *American Economic Review* 35, no. 4 (1945): 519.

29. Hayek, "The Use of Knowledge in Society," 521–522.

30. Hayek, "The Use of Knowledge in Society," 521–522.

31. Hayek, "The Use of Knowledge in Society," 523, 526.

32. Hayek, "The Use of Knowledge in Society," 521. That is, competition is the most "efficient" means of planning since it makes the "full[est] use of the existing knowledge" (521).

33. Hayek, "The Use of Knowledge in Society," 525.

34. Hayek, "The Use of Knowledge in Society," 526.

35. Philip Mirowski, "Twelve Theses Concerning the History of Postwar Neoclassical Price Theory," *History of Political Economy* 38 (2006): 343–379.

36. On the multiple origins of evolutionary computing, see David B. Fogel, *Evolutionary Computation: The Fossil Record* (Hoboken, NJ: John Wiley & Sons, 1998), xi–xii. Fogel dates the term "evolutionary computation" to 1991 (1).

37. For early attempts to use computers to model natural evolution, see A. S. Fraser, "Simulation of Genetic Systems by Automatic Digital Systems. I. Introduction," *Australian Journal of Biological Sciences* 10 (1957): 484–491, reprinted in Fogel, *Evolutionary Computation*, 87–94; and Crosby, "Computers in the Study of Evolution," reprinted in Fogel, *Evolutionary Computation*, 95–108. For early attempts to "evolve" industrial productivity, see G. E. P. Box, "Evolutionary Operation: A Method for Increasing Industrial Productivity," *Applied Statistics* 6, no. 2 (1957): 81–101, reprinted in Fogel, *Evolutionary Computation*, 121–141. For early attempts to create artificial intelligence, see Fogel, Owens, and Walsh, "Artificial Intelligence through a Simulation

of Evolution," 131–155, reprinted in Fogel, *Evolutionary Computation*, 230–254. On fluid mechanics, see I. Rechenberg, "Cybernetic Solution Path of an Experimental Problem," *Royal Aircraft Establishment, Library Translations*, no. 1122 (1965), reprinted in Fogel, *Evolutionary Computation*, 297–309.

38. The importance of cybernetics was stressed explicitly in some of these early articles: Rechenberg, for example, contended that "in cybernetics it is axiomatic that common theories can be applied to apparently widely separated fields of science. The increasingly evident points in common between biology as the theory of organisms and technology as the theory of mechanisms provide a good example of this" (Rechenberg, "Cybernetic Solution Path," reprinted in Fogel, *Evolutionary Computation*, 301). And though computer scientists and biologists did not always directly influence or work with one another in this early period of evolutionary computation, there were occasions in which they presented their work to one another. A notable example was a 1966 conference titled "Mathematical Challenges to the Neo-Darwinian Interpretation of Evolution," held at the Wistar Institute of Anatomy and Biology. This conference brought together biologists such as Richard Lewontin, Ernst Mayr, Peter Medawar, Sewall Wright, and C. H. Waddington with computer scientists and bioengineers such as Murray Eden, W. Bossert, and Nils Barracelli. See Paul S. Moorhead and Martin M. Kaplan, eds., *Mathematical Challenges to the Neo-Darwinian Interpretation of Evolution* (Philadelphia: Wistar Institute Press, 1967).

39. Fogel, *Evolutionary Computation*, 3.

40. Fogel, *Evolutionary Computation*, 4.

41. This example is taken from Dan Simon, *Evolutionary Optimization Algorithms: Biologically-Inspired and Population-Based Approaches to Computer Intelligence* (Hoboken, NJ: John Wiley & Sons, 2013), 44–49.

42. For an early example of this approach to industrial productivity, see Box, "Evolutionary Operation."

43. As Frank Rosenblatt noted near the start of his first article on perceptrons, "the most suggestive work, for the standpoint of the following theory [i.e., the theory that Rosenblatt develops in the article], is that of Hebb and Hayek." See Rosenblatt, "The Perceptron: A Probabilistic Model for Information Storage and Organization in the Brain," *Psychological Review* 65, no. 6 (1958): 386–408, at 388.

44. Rosenblatt, "Perceptron," 388–389.

45. Rosenblatt, "Perceptron," 388.

46. Rosenblatt discusses the role of training in "The Perceptron" (395) and at more length in *Principles of Neurodynamics: Perceptrons and the Theory of Brain Mechanisms* (Washington, DC: Spartan Books, 1962).

47. Rosenblatt, *Principles of Neurodynamics*, 388.

48. Hayek, "The Use of Knowledge in Society," 526.

49. Hayek, "The Use of Knowledge in Society," 522.

50. Hayek, "The Use of Knowledge in Society," 526.

51. Rosenblatt, *Principles of Neurodynamics*, 17.

52. Rosenblatt, *Principles of Neurodynamics*, 19–20; emphasis added.

53. When studying perceptrons, the "object of analysis is an experimental system which includes the perceptron, a defined environment, and a training procedure or agency" (Rosenblatt, *Principles of Neurodynamics*, 27–28).

54. For discussion of these data sets, see Aurélien Géron, *Hands-On Machine Learning with Scikit-Learn and TensorFlow: Concepts, Tools, and Techniques to Build Intelligent Systems* (Sebastopol, CA: O'Reilly Media, 2017), 33–34.

55. Donella H. Meadows et al., *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind* (New York: Universe Books, 1972), 9.

56. Meadows et al., *The Limits to Growth*, 9.

57. Meadows et al., *The Limits to Growth*, 12.

58. For an early discussion of the background of, as well as responses to, *The Limits to Growth*, see Francis Sandbach, "The Rise and Fall of the Limits to Growth Debate," *Social Studies of Science* 8, no. 4 (1978): 495–520; for a more recent discussion, see Elodie Vieille Blanchard, "Modelling the Future: An Overview of the 'Limits to Growth' Debate," *Centaurus* 52 (2010): 91–116. For a discussion focused primarily on Forrester, see Fernando Elichirigoity, *Planet Management: Limits to Growth, Computer Simulation, and the Emergence of Global Spaces* (Evanston, IL: Northwestern University Press, 1999). See also Melinda Cooper, *Life as Surplus: Biotechnology and Capitalism in the Neoliberal Era* (Seattle: University of Washington Press, 2008), 15–50. As Elichirigoity notes in *Planet Management*, Malthus's approach to population was the subject of some of the early presentations at MIT that led to *The Limits to Growth* (88).

59. Jay W. Forrester, *Industrial Dynamics* (Cambridge, MA: MIT Press, 1961).

60. Meadows et al., *The Limits to Growth*, 23.

61. Meadows et al., *The Limits to Growth*, 24.

62. On President Carter's commission, see Cooper, *Life as Surplus*, 17.

63. For an overview of these various responses, see Blanchard, "Modelling the Future."

64. On the connection between *The Limits to Growth* and the development of the Chinese one-child policy, see Susan Greenhalgh and Edwin A. Winckler, *Governing China's Population: From Leninist to Neoliberal Biopolitics* (Stanford, CA: Stanford University Press, 2005), 291–300. See also Carole R. McCann, *Figuring the Population Bomb: Gender and Demography in the Mid-twentieth Century* (Seattle: University of Washington Press, 2016).

65. For the linkages between the world dynamics computer modeling employed in *The Limits to Growth* and climate modeling, see Paul N. Edwards, *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming* (Cambridge, MA: MIT Press, 2010), 366–372.

66. On neoliberal criticisms of *The Limits to Growth*, see Cooper, *Life as Surplus*, 15–50.

67. The original academic papers that described Google's system include Sergey Brin and Lawrence Page, "The Anatomy of a Large-Scale Hypertextual Web Search Engine" (working paper, Stanford InfoLab, Stanford University, accessed March 6, 2016,

http://infolab.stanford.edu/~backrub/google.html); and Lawrence Page, Sergey Brin, Rajeev Motwani, and Terry Winograd, "The PageRank Citation Ranking: Bringing Order to the Web," Technical Report, Stanford InfoLab, 1999, http://ilpubs.stanford.edu:8090/422/. For accounts of the history and technical aspects of Google's PageRank approach, see Amy N. Lanville and Carl D. Meyer, *Google's PageRank and Beyond: The Science of Search Engine Rankings* (Princeton, NJ: Princeton University Press, 2006); Michael W. Berry and Murray Browne, *Understanding Search Engines: Mathematical Modeling and Text Retrieval* (Philadelphia: Society for Industrial and Applied Mathematics, 2005). For a useful critical account of the value logic of PageRank, see Matteo Pasquinelli, "Google's PageRank Algorithm: A Diagram of the Cognitive Capitalism and the Rentier of the Common Intellect," in *Deep Search: The Politics of Search Beyond Google*, ed. Konrad Becker and Felix Stalder (London: Transaction Publishers, 2009), 152–162, http://matteopasquinelli.com/google-pagerank-algorithm/.

68. It is worth stressing that in academia the formal system of numerical article and journal ranking dates back only to the mid-1960s and has developed in a decidedly neoliberal direction in the last two decades; see Philip Mirowski, *Science-Mart: Privatizing American Science* (Cambridge, MA: Harvard University Press, 2011), 266–287. As a consequence, PageRank was based on a very specific, recent—and, as Mirowski convincingly argues—neoliberal model of academic expert communities.

69. "One can simply think of every link as like an academic citation," and thus a "major page like http://www.yahoo.com/ will have tens of thousands of backlinks (or citations) pointing to it": Page et al., "The PageRank Citation Ranking," 2.

70. Page et al., "The PageRank Citation Ranking," 1. PageRank was thus a "method for computing a ranking for every web page based on the graph of the web" (2) with "graph" here understood to mean the number and nature of links to every page.

71. Page et al., "The PageRank Citation Ranking," 2.

72. Nicholas Carr, *The Big Switch: Rewiring the World, from Edison to Google* (New York: W. W. Norton, 2008).

73. Pasquinelli, "Google's PageRank Algorithm."

74. Page et al., "The PageRank Citation Ranking," 12.

75. Chicago school neoliberal Milton Friedman stressed this point in his classic essay "The Methodology of Positive Economics," included in Friedman, *Essays in Positive Economics* (Chicago: University of Chicago Press, 1953), 3–43.

76. On the emergence of Wikipedia, see Nathaniel Tkacz, *Wikipedia and the Politics of Openness* (Chicago: University of Chicago Press, 2014). (Tracz emphasizes that Wikipedia redefined, rather than eliminated, expertise—a point that holds more generally for both Hayek, for whom the neoliberal economist's expertise must be trusted when it comes to clarifying how to optimize the market, and for the smart developments we discuss.) For a critical account of the development of open-source and citizen science that emphasizes the ways in which these efforts have been encouraged and coordinated with for-profit platforms, see Philip Mirowski, "The Future(s) of Open Science," *Social Studies of Science* 48, no. 2 (2018): 171–203.

77. Klein, "Screen New Deal."

CHAPTER 2

1. From the start, the competition was plagued by criticism: the cost of entry for junior architects or designers was prohibitive, and all the chosen designs came from well-known and well-established architectural firms linked to the most prestigious and storied architecture schools in New York, such as Columbia University. In addition, the projected designs were not evaluated for feasibility or environmental impact and were critiqued for supporting progrowth ideologies and the dispossession of urban poor and minority communities. See Justin Davidson, "MOMA's Schemes for Fixing Urban Problems Are Either Too Dainty or Too Sweeping," *The Vulture*, November 20, 2014, https://www.vulture.com/2014/11/review-momas-uneven-growth.html; Stephanie Wakefield and Bruce Braun, "Oystertecture: Infrastructure, Profanation, and the Sacred Figure of the Human," in *Infrastructure, Environment and Life in the Anthropocene*, ed. Kregg Hetherington (Durham, NC: Duke University Press, 2019), 193–215.

2. Barry Bergdoll, "Introductory Statement," Museum of Modern Art, accessed November 3, 2016, https://www.moma.org/explore/inside_out/rising-currents?x-iframe=true#description. The website no longer exists, but similar materials can be accessed at https://www.moma.org/calendar/exhibitions/1028.

3. Kate Orff, "Oyster-tecture," Scape Landscape Architecture DCP, accessed December 10, 2020, https://www.scapestudio.com/projects/oyster-tecture/.

4. nArchitects, "Aqueous City," Museum of Modern Art, accessed April 16, 2017, http://narchitects.com/work/moma-rising-currents/. The website no longer exists, but the project is available (as of 2021) at https://www.youtube.com/watch?v=O7folAgxX-gaqueous.

5. Lisa Wirthman, "NYC's Hudson Yards Looks towards the Future of Smart Development," *Forbes*, October 3, 2018.

6. Aria Bendix, "New York's $25 Billion Megadevelopment Can Withstand a Superstorm or Terrorist Attack—Even If the Entire City Shuts Down," Business Insider, March 14, 2019, https://www.businessinsider.com/hudson-yards-can-withstand-superstorm-terrorist-attack-2019-3; Matthew Schuerman, "Climate Change Fears Meet Development at the New Hudson Yards," WNYC News, December 12, 2012, https://www.wnyc.org/story/256763-underside-developing-hudson-yards/.

7. See also Orit Halpern and Gokce Günel's discussion of "preemptive hopefulness" in their "Demoing unto Death: Smart Cities, Environment, and Preemptive Hope," *FibreCulture*, no. 29 (2017), http://twentynine.fibreculturejournal.org/fcj-215-demoing-unto-death-smart-cities-environment-and-preemptive-hope/.

8. Ash Amin, "On Urban Failure," *Social Research* 83, no. 3 (2016): 778. See also Ayona Datta, "Postcolonial Urban Futures: Imagining and Governing India's Smart Urban Age," *Environment and Planning D: Society and Space* 37, no. 3 (2019): 393–410.

9. As we hope will be evident in what follows, we treat Negroponte in this chapter primarily as a channel or conduit for interests and tendencies (and tensions) already present at MIT, in Boston, and in 1960s and 1970s urban planning, architecture, and computing more generally. Many of the concepts that we attribute specifically to

Negroponte can also be found in the work of other MIT faculty. For example, Warren Brodey, originally a psychiatrist and psychoanalyst and then an MIT cybernetics enthusiast before eventually becoming a Maoist organizer abroad, also promoted notions of “soft” architecture and human-machine urban design in the late 1960s. He was specifically acknowledged by Negroponte in *The Architecture Machine* and cited several times in both *The Architecture Machine* and *Soft Architecture Machines*.

10. Molly Wright Steenson, “Architectures of Information: Christopher Alexander, Cedric Price, and Nicholas Negroponte and the MIT Architecture Machine Group” (PhD diss., Princeton University, 2014). See also Molly Wright Steenson, *Architectural Intelligence* (Cambridge, MA: MIT Press, 2017).

11. Nicholas Negroponte, *The Architecture Machine* (Cambridge, MA: MIT Press, 1970), i.

12. Negroponte, *The Architecture Machine*.

13. Negroponte, *The Architecture Machine*, 55.

14. Negroponte, *The Architecture Machine*.

15. Negroponte, *The Architecture Machine*, 57.

16. Significantly, this demo project involved no actual computers, for at the time, computers could not handle such sophisticated questions, and the test was in fact secretly run by a human being. The participants, however, were kept ignorant of this fact, believing that they were speaking to a machine. One can read, therefore, the whole test as an interface to and a demo of what a computationally aided interaction in service of a responsive government might be. Negroponte, *The Architecture Machine*, 55–58.

17. Negroponte, *The Architecture Machine*, 55–56.

18. Negroponte, *The Architecture Machine*, 56.

19. Nicholas Negroponte, “Systems of Urban Growth” (BA thesis, Massachusetts Institute of Technology, 1965). In the preface to his thesis, Negroponte noted that the topic of “population”—which for him meant the “study of how populations live, what populations want, and, primarily, how populations expand”—provided him with a “vantage point” that allowed him to develop his more primary interest in “the city as an organism,” i.e., “a machine of communication.”

20. Stephen Graham and Simon Marvin, *Splintering Urbanism: Networked Infrastructures, Technological Mobilities and the Urban Condition* (London: Routledge, 2001), 111.

21. See Peter Dreier, “Downtown Development and Urban Reform: The Politics of Boston’s Linkage Policy,” *Urban Affairs Quarterly* 26, no. 3 (1991): 354–370; Melvin King, *Chain of Change: Struggles for Black Community Development* (Boston: South End Press, 1981). See also “MIT’s Community Fellows Program,” MIT School of Architecture and Planning, accessed December 10, 2015, http://web.mit.edu/mhking/www/cfp.html.

22. Edward Murray Bassett, *Zoning* (1922; repr., New York: Russell Sage Foundation, 1940), 330.

23. Frank Backus Williams, *Building Regulation by Districts: The Lesson of Berlin* (New York: National Housing Association, 1914), 1.

24. Negroponte, *The Architecture Machine*, 67.

25. Nicholas Negroponte, *Soft Architecture Machines* (Cambridge, MA: MIT Press, 1975), 103.

26. Negroponte, *Soft Architecture Machines*, 119.

27. Jennifer Light, *From Warfare to Welfare: Defense Intellectuals and Urban Problems in Cold War America* (Baltimore: John Hopkins University Press, 2003).

28. Orit Halpern, *Beautiful Data: A History of Vision and Reason since 1945* (Durham, NC: Duke University Press, 2015), 79–199; Jay W. Forrester, *Industrial Dynamics* (Cambridge, MA: MIT Press, 1961); Jay W. Forrester, *Urban Dynamics* (Cambridge, MA: MIT Press, 1969); Kevin Lynch, *The Image of the City* (Cambridge, MA: MIT Press, 1960).

29. Matthew W. Hughey, "Of Riots and Racism: Fifty Years since the Best Laid Schemes of the Kerner Commission (1968–2018)," *Sociological Forum* 33, no. 3 (2018): 627.

30. Fenwick McKelvey, "The Other Cambridge Analytics: Early 'Artificial Intelligence' in American Political Science," in *The Cultural Life of Machine Learning: An Incursion into Critical AI Studies*, ed. Jonathan Roberge and Michael Castelle (Cham, Switzerland: Palgrave Macmillan/Springer Nature Switzerland AG, 2020), internal quotes from MIT Archives, 132. For more material on Simulmatics and the question of automating democracy, see Jill Lepore, *If Then: How the Simulmatics Corporation Invented the Future* (New York: Liveright, 2020).

31. Forrester, *Urban Dynamics*, 1.

32. Forrester, *Urban Dynamics*, ix–x, 14–18, 107–115.

33. Forrester, *Urban Dynamics*, ix–x, 12–17.

34. Daniel M. Abramson, *Obsolescence: An Architectural History* (Chicago: University of Chicago Press, 2016).

35. Robert Fishman, *Urban Utopias in the Twentieth Century: Ebenezer Howard, Frank Lloyd Wright, and Le Corbusier* (Cambridge, MA: MIT Press, 1982).

36. Shannon Mattern, "Interfacing Urban Intelligence," *Places Journal*, April 14, 2014, https://placesjournal.org/article/interfacing-urban-intelligence/.

37. Negroponte, *The Architecture Machine*, 2.

38. Steve Heims, *The Cybernetics Group* (Cambridge, MA: MIT Press, 1991); Peter Galison, "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision," *Critical Inquiry* 21 (1994): 228–266.

39. Norbert Wiener, *Cybernetics; or, Control and Communication in the Animal and the Machine* (Cambridge, MA: MIT Press, 1961).

40. The pair would go to MIT in 1952 at Wiener's behest.

41. Lily E. Kay, "From Logical Neurons to Poetic Embodiments of Mind: Warren McCulloch's Project in Neuroscience," *Science in Context* 14, no. 4 (2001): 591–614.

42. Warren McCulloch and Walter Pitts, "A Logical Calculus of Ideas Immanent in Nervous Activity," in *Embodiments of Mind*, ed. Warren McCulloch (1943; repr., Cambridge, MA: MIT Press, 1970).

43. Frank Rosenblatt, "The Perceptron: A Probabilistic Model for Information Storage and Organization in the Brain," *Psychological Review* 65, no. 6 (1958): 386.

44. Rosenblatt, "The Perceptron," 387.

45. Rosenblatt, "The Perceptron," 388.

46. Oliver G. Selfridge, "Pandemonium: A Paradigm for Learning," in *Proceedings of the Symposium on Mechanisation of Thought Processes*, ed. D. V. Blake and A. M. Uttley (London: Her Majesty's Stationery Office, 1959), 511–529. Arch Mac also engaged the ideas of Marvin Minsky, Warren McCulloch, and Ross Ashby, according to Nicholas Negroponte's accounts at the start of *The Architecture Machine* and *Soft Architecture Machines*.

47. Branden Hookway, *Pandemonium: The Rise of Predatory Locales in the Postwar World* (Princeton, NJ: Princeton Architectural Press, 1999).

48. Selfridge, "Pandemonium," 513.

49. Hookway, *Pandemonium*.

50. Negroponte, *Soft Architecture Machines*, viii.

51. Lian Chikako Chang, "Live Blog—Mohsen Mostafavi in Conversation with Nicholas Negroponte," *Archinect* (blog), January 15, 2013, https://archinect.com/lian/live-blog-mohsen-mostafavi-in-conversation-with-nicholas-negroponte.

52. Andrew Lippman, interview by Orit Halpern, November 25, 2014, MIT Media Lab. The background of the movie map in relation to DARPA is also discussed by Michael Naimark, "Aspen the Verb: Musings on Heritage and Virtuality," *Presence Journal* 15, no. 3 (2006), http://www.naimark.net/writing/aspen.html.

53. Noah Wardrip-Fruin and Nick Montfort, eds., *The New Media Reader* (Cambridge, MA: MIT Press, 2003), chaps. 17, 23; Marisa Rennee Brandt, "War, Trauma, and Technologies of the Self: The Making of Virtual Reality Exposure Therapy" (PhD diss., University of San Diego, 2013).

54. Naimark, "Aspen the Verb"; Michael Naimark, interview by Orit Halpern, August 12, 2013, Cambridge, MA.

55. Naimark, interview. Naimark informed Halpern that they went out at the same time every day to record footage.

56. Lian Chikako Chang, "Live Blog—Mohsen Mostafavi in Conversation with Nicholas Negroponte."

57. Felicity Scott, "Aspen Proving Grounds" (paper presented at Technics and Art: Architecture, Cities, and History after Mumford, Columbia University, 2012).

58. Tristan d'Estrée Sterk, "Building upon Negroponte: A Hybridized Model of Control Suitable for Responsive Architecture," *Automation in Construction* 14, no. 2 (2014): 225–232.

59. Larry D. Busbea, *The Responsive Environment: Design Aesthetics and the Human in the 1970's* (Minneapolis: University of Minnesota Press, 2019), xx.

60. Negroponte, *Soft Architecture Machines*, 103.

61. Negroponte, *Soft Architecture Machines*, 103–104.

62. Rebecca Slayton, "Efficient, Secure, Green: Digital Utopianism and the Challenge of Making the Electrical Grid 'Smart,'" *Information and Culture* 48, no. 4 (2013): 448–478, 461–462.

63. Slayton, "Efficient, Secure, Green," 454.

64. On the role played by *The Limits to Growth*, see Slayton, "Efficient, Secure Green," 455, 474n43.

65. Slayton, "Efficient, Secure, Green," 457.

66. Slayton, "Efficient, Secure, Green."

67. Slayton, "Efficient, Secure, Green," 458.

68. Kurt E. Yeager, "Creating the Second Electrical Century," *Public Utilities Fortnightly* 126 (1990): 1, cited in Slayton, "Efficient, Secure Green," 458.

69. Khoi Vu, Miroslav Begovic, and Damir Novosel, "Grids Get Smart Protection and Control," *IEEE Computer Applications in Power* 10, no. 4 (1997): 40, cited in Slayton, "Efficient, Secure Green," 462.

70. Vu, Begovic, and Novosel, "Grids Get Smart Protection and Control," 41. Slayton notes that after the terrorist attacks on the World Trade Center in 2011, smartness was also charged with preventing terrorist attacks on the electrical grid (Slayton, "Efficient, Secure Green," 464).

71. As Slayton notes in "Efficient, Secure, Green," "Unfortunately, by [using smart technologies to] operat[e] large areas closer to margins of error, utilities also risked failures on an even larger scale, and blackouts increased in frequency and size through the 1990s and early new millennium" (462).

72. H. Res. 109 (2019), at 8.

73. Winona LaDuke and Deborah Cowen, "Beyond Wiindigo Infrastructure," *South Atlantic Quarterly* 119, no. 2 (2020): 243–268, 245.

74. Dave Lovekin, "Unlocking Clean Energy Opportunities for Indigenous Communities: Federal Funding Will Help Communities Develop Renewable Energy Projects and Transition Off Diesel," Pembina Institute, February 24, 2017, https://www.pembina.org/blog/unlocking-clean-energy-opportunities-indigenous-communities.

75. Krista Allen, "NTUA, Kayenta Solar Project Chart Path to the Future," *Navajo Times*, October 3, 2019, https://navajotimes.com/biz/ntua-kayenta-solar-project-chart-path-to-the-future/.

76. Jannine Anderson, "Navajo Solar Project Sending Power to the Grid in Kayenta, Ariz.," *American Public Power Association*, June 20, 2017; Bonnie Riva Ras, "The Navajo Nation's First Solar Project Is Scaling Up," *Goodnet: Gateway to Doing Good*, January 20, 2019, https://www.goodnet.org/articles/navajo-nations-first-solar-project-scaling-up. LaDuke and Cowen note that the Navajo Nation has seen very few benefits from the agreements signed in the 1920s that promised royalties for uranium, oil, gas, and coal extraction on their lands. Although the Nation provided enough energy to power the entire state of New Mexico 32 times over, 85 percent of Nation households had no electricity before the panels went online in 2017 (256).

77. Allen, "NTUA, Kayenta Solar Project Chart Path to the Future." See also Patty Garcia-Likens, "NTUA, SRP and Navajo Nation Leaders Celebrate Groundbreaking Ceremony for Kayenta II," SRP, August 27, 2018, https://media.srpnet.com/kayenta-ii-groundbreaking-ceremony/.

78. Allen, "NTUA, Kayenta Solar Project Chart Path to the Future."

79. Negroponte, *The Architecture Machine*, 1.

80. See Robert E. Park, "The City as a Social Laboratory," in *Chicago: An Experiment in Social Science Research*, ed. Thomas Vernor Smith and Leonard Dupee White (Chicago: University of Chicago Press, 1929), 1–19, as well as the other essays in that volume. This early twentieth-century University of Chicago sociology approach to experimentation has been an important reference point for several recent geographers who advocate for experimental geography; see, e.g., Matthias Gross and Wolfgang Krohn, "Society as Experiment: Sociological Foundations for a Self-Experimental Society," *History of the Human Sciences* 18, no. 2 (2005): 63–86; and Andrew Karvonen and Bas Van Heur, "Urban Laboratories: Experiments in Reworking Cities," *International Journal of Urban and Regional Research* 38, no. 2 (2014): 379–392.

81. Park, "The City as a Social Laboratory," 9.

82. Park, "The City as a Social Laboratory," 1, 15.

83. While Aristotle did not employ the term "ζώνη" (belt) in his fivefold division of the earth, the terminology of zones was subsequently attached to his schema. See Aristotle, *Meteorologica*, trans. H. D. P. Lee (Cambridge, MA: Harvard University Press, 2014), 2.5, 362a32. These terrestrial zones were defined by the angle at which the sun hit them, and each zone was understood as possessing its own particular set of conditions: the torrid zone, for example, was presumed to be uninhabitable due to its extreme heart.

84. For example, L. A. Borradaile contended in *The Animal and Its Environment* (London: Henry Frowde and Hodder and Stoughton, 1923) that "*Mountains* have not one but many faunas. A high mountain is a microcosm. As it ascends from the plain it bears zones whose climates are such as would be passed through in travelling from it to the nearer of the poles. In the tropics it will have first a tropical zone, forested or arid as the case may be; then others that are sub-tropical; temperate, with deciduous trees; cold, with grass and flowers passing into mosses and lichens; and, finally, snow-covered throughout the year" (309–310).

85. In *Chicago: An Experiment in Social Planning*, Park's colleague Ernest W. Burgess drew on the older sense of zones in his suggestion that modern cities naturally—-i.e., in the absence of explicit planning—end up divided into five zones: "The Central Business District," "The Zone in Transition," "The Zone of Independent Workingmen's Homes," "The Zone of Better Residences," and "The Commuters' Zone" (114–117). The point of urban zoning plans was to replace, or at least guide, this natural zonal division of the city with zones planned by experts who drew on information gathered about the city. While early twentieth-century advocates of zoning had argued that zoning was *not* a method for enabling urban experiments—"there will be a temptation for radical individuals and officials to use zoning as a field for experimentation," Bassett noted in *Zoning*, but "this is

a mistake" (328)—it clearly was an experiment in the sense used by Park and his colleagues.

86. In the US, the 1934 Act to Provide for the Establishment, Operation, and Maintenance of Foreign-Trade Zones in Ports of Entry of the United States, to Expedite and Encourage Foreign Commerce, and for Other Purposes, H.R. 9322, Public No. 397, established the first free-trade zones. In her influential *Extrastatecraft: The Power of Infrastructure Space* (New York: Verso, 2014), Keller Easterling follows Guangwen Meng and R. J. McCalla in tracing the twentieth-century free-trade zone to a centuries-long lineage of "free" ports, which include the ancient Roman port of Delos in Greece and Hanseatic free port cities such as Hamburg. While this is in one sense correct, such a long durée account does not help us to understand why the term "zone" was specifically employed in the 1930s and misses the key fact, stressed by early twentieth-century advocates of zoning, that zones striated the unit of the cities; this was in contrast to free ports and cities, which were free in their entirety, so to speak.

87. Negroponte, *The Architecture Machine*, 185.

88. Negroponte, *The Architecture Machine*, 118.

89. In *Fundamentals of Ecology*, for example, Eugene P. Odum defined ecotones as "a junction zone or tension belt" (56; see also 57, 207). In *Imperial Eyes: Travel Writing and Transculturation* (London: Routledge, 1992), Mary Louise Pratt defined a contact zone as "the space of colonial encounters, the space in which peoples geographically and historically separated come into contact with each other and establish ongoing relations, using involving conditions of coercion, radical inequality, and intractable contact" (6); the term "is an attempt to invoke the spatial and temporal copresence of subjects previously separated but geographic and historical disjunctures, and whose trajectories now intersect" (7). In *Image and Logic* (Chicago: University of Chicago Press, 1997), Peter Galison used the term "trading zone" to get at the fact that "two groups can agree on rules of exchange even if they ascribe utterly different significance to the objects being exchanged; they may even disagree on the meaning of the exchange process itself. Nonetheless, the trading partners can hammer out a local coordination, despite vast global differences. In an even more sophisticated way, cultures in interaction frequently establish contact languages, systems of discourse that can vary from the most function-specific jargons, through semispecific pidgins, to full-fledged creoles rich enough to support activities as complex as poetry and metalinguistic reflection" (783). Latour and Peter Weibel discuss critical zones in *Critical Zones: The Science and Politics of Landing on Earth* (Cambridge, MA: MIT Press, 2020).

90. See, for example, Richard Neutra, "Comments on Planetary Reconstruction," *Arts and Architecture* 61, no. 12 (December 1944): 20–22; Neutra, "Projects of Puerto Rico: Hospitals, Health Centers, and Schools," *Architecture d'Aujourd'hui* 16, no. 5 (May 1946): 71–77; and Neutra, "Designs for Puerto Rico (A Test Case)," Richard and Dion Neutra Papers, collection no. 1,179, Department of Special Collections, Charles E. Young Research Library, University of California, Los Angeles, 1943. In these articles he labels the project a "test" and an "experiment." We thank Daniel Barber for alerting us to, and sharing, these materials.

91. Ginger Nolan, "Quasi-urban Citizenship: The Global Village as 'Nomos of the Modern,'" *Journal of Architecture* 23 (2018): 448–470. As Nolan notes, McLuhan was influenced by ethnopsychiatrist John Colin Carothers, who arrived in Kenya in the 1950s to advise British colonial authorities in their war against the Kenya Land and Freedom Army. Carothers recommended a policy of village-isation, essentially a system of forced detention in camps, as an antidote to mass collective organization in urban areas. Such ideas of a decentralized but networked system that would "buffer" denizens from the impacts of contemporary society (or its politics) inhere within contemporary fantasies of smartness as a logic to negotiate precarity and uncertainty. For critiques that stress how computing continues colonial discourses, see Kavita Philip, "The Internet Will Be Decolonized," in *Your Computer Is on Fire*, ed. Benjamin Peters, Thomas S. Mullaney, Mar Hicks, and Kavita Philip (Cambridge, MA: MIT Press, 2021), Kindle, location 2607.

92. Adam Moe Fejerskov, "The New Technopolitics of Development and the Global South as a Laboratory of Technological Experimentation," *Science, Technology, and Human Values* 42 (2017): 947–968; Kaushik Sunder Rajan, *Pharmocracy: Value, Politics, and Knowledge in Global Biomedicine* (Durham, NC: Duke University Press, 2017).

93. Ministry of Housing and Urban Affairs, Government of India, Smartnet, accessed March 9, 2022, https://smartnet.niua.org/; Nishant Shah, "Identity and Identification: The Individual in the Time of Networked Governance," *Socio-Legal Review* 11, no. 2 (2015): 22–40.

94. See Datta, "Postcolonial Urban Futures."

95. The contemporary project of so-called smart growth—also known as "new urbanism" and "sustainable development"—represents a partial approach to Negroponte's vision. Smart growth seeks to limit urban sprawl, increase use of public transportation, diversify neighborhoods, and preserve rural areas but aims to achieve these ends via economic inducements (e.g., tax credits) for development that follows these principles, rather than explicit zoning regulation. Thus, though the smartness of smart urban growth refers most explicitly to its attempts to align urban population growth with environmental and quality-of-life goals, it also references the premise that such alignment cannot be achieved by direct government regulation but only by economic inducements that are variably taken up by populations. On smart growth, see T. Chapin, "Introduction: From Growth Controls, to Comprehensive Planning, to Smart Growth: Planning's Emerging Fourth Wave," *Journal of the American Planning Association* 78, no. 1 (2012): 5–15; and J. M. DeGrove, *Planning Policy and Politics: Smart Growth and the States* (Cambridge, MA: Lincoln Institute of Land Policy, 2005).

96. Yuriko Furuhata, "Multimedia Environments and Security Operations: Expo '70 as a Laboratory of Governance," *Grey Room*, no. 54 (Winter 2014): 56–79, 59.

97. Matt Shaw, "Why Arata Isozaki Deserves the Pritzker," *The Architect's Newspaper*, April 16, 2019, https://www.archpaper.com/2019/04/arata-isozaki-pritzker/.

CHAPTER 3

1. Fischer Black, "Noise," *Journal of Finance* 41, no. 3 (1986): 529–543, 529.

2. For more on the relationship between histories of science and models of communication and economics, see Philip Mirowski, *Machine Dreams: Economics Becomes a Cyborg Science* (New York: Cambridge University Press, 2002); and Claude Shannon and Warren Weaver, *The Mathematical Theory of Communication* (1963; repr., Urbana-Champaign: University of Illinois Press, 1998). For a historical discussion about labor, work, and thermodynamics, see Anson Rabinbach, *The Human Motor: Energy, Fatigue, and the Origins of Modernity* (Berkeley: University of California Press, 1992).

3. For work on entropy and cybernetics, see N. Katherine Hayles, *How We Became Posthuman: Virtual Bodies in Cybernetics, Literature, and Informatics* (Chicago: University of Chicago Press, 1999); and Orit Halpern, "Dreams for Our Perceptual Present: Temporality, Storage, and Interactivity in Cybernetics," *Configurations* 13, no. 2 (2005): 285–321.

4. Black, "Noise," 529.

5. For an extensive discussion of thermodynamics, stochastic processes, and control, see the introduction to Norbert Wiener, *Cybernetics; or, Control and Communication in the Animal and the Machine* (Cambridge, MA: MIT Press, 1961); for further discussion, see also Halpern, "Dreams for Our Perceptual Present," and Peter Galison, "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision," *Critical Inquiry* 21 (1994): 228–266.

6. Black was an applied mathematician who had been trained by artificial intelligence pioneer Marvin Minsky, Scholes was a Canadian American economist from the University of Chicago who came to MIT after earning his PhD under Eugene Fama, and Merton was an economist trained at MIT. The equation we discuss here is sometimes called the Black-Scholes option pricing model, while others call this the Black-Scholes derivative pricing model, and we employ the latter terminology. While these three figures are not singularly responsible for global financialization, their history serves as a mirror of a situation in which new computational techniques were produced to address geopolitical-environmental transformations. See George G. Szpiro, *Pricing the Future: Finance, Physics, and the 300 Year Journey to the Black-Scholes Equation* (New York: Basic Books, 2011), 116–117, Kindle.

7. Randy Martin, "What Difference Do Derivatives Make? From the Technical to the Political Conjuncture," *Culture Unbound* 6 (2014): 189–210, 193.

8. For an account of earlier nineteenth- and twentieth-century models for pricing options, see Donald A. MacKenzie, *An Engine, Not a Camera: How Financial Models Shape Markets* (Cambridge, MA: MIT Press, 2006), 37–88.

9. Black and Scholes were not the first to treat the movement of stock prices as random, and they drew upon a tradition of research that stretched back to the early twentieth century; see MacKenzie, *An Engine, Not a Camera*, 56–66. However, they were the first to embed this premise in the mathematical structure of an investment tool that subsequently became widely used.

10. Black, "Noise," 5, cited in MacKenzie, *An Engine, Not a Camera*, 321n18.

11. Robert Merton added the concept of continuous time and figured out a derivation equation to smooth the curve of prices. The final equation is essentially the merger of a normal curve with Brownian motion; see Satyajit Das, *Traders, Guns, and Money: Knowns and Unknowns in the Dazzling World of Derivatives* (Edinburgh: Prentice Hall, 2006), 194–195.

12. MacKenzie, *An Engine, Not a Camera*, 60–67.

13. A "portfolio" is a collection of multiple investments that vary in their presumed riskiness and that aim to maximize profit for a specific level of overall risk; "arbitrage" refers to purportedly risk-free investments, such as the profit that can be made when one takes advantage of slight differences between currency exchanges—or the price of the same stock—in two different geographical locations.

14. Nick Srnicek, *Platform Capitalism* (New York: Polity Press, 2016); Shoshana Zuboff, *The Age of Surveillance Capitalism* (New York: Hachette Book Group, 2019).

15. Sarah Barns, for example, points out that the "'Uber model' isn't just for Uber, it's for any utility or infrastructure to try to adopt." Thus, "platform strategy," she argues, is an urban strategy to build digital services "in ways that ensure end users are also producers of sorts" and is part of a broader sharing economy that facilitates the intensified extraction of value from existing infrastructures. Sarah Barns, *Platform Urbanism: Negotiating Platform Ecosystems in Connected Cities* (Singapore: Palgrave Macmillan, 2020), 15. For more on Uber and platform urbanism, see Andrea Pollio, "Uber, Airports, and Labour at the Infrastructural Interfaces of Platform Urbanism," *Geoforum* 118 (January (2021): 47–55; and Arun Sundararjan, *The Sharing Economy: The End of Employment and the Rise of Crowd-Based Capitalism* (Cambridge, MA: MIT Press, 2016).

16. See Niels van Doorn, "A New Institution on the Block: On Platform Urbanism and Airbnb Citizenship," *New Media and Society* 22, no. 10 (2020): 1808–1826; Tarik Dogru, Mody Makarand, Courtney Suess, Nathan Line, and Mark Bonn, "Airbnb 2.0: Is It a Sharing Economy Platform or a Lodging Corporation?," *Tourism Management* 78 (2020): 1–5. AirBnb is also discussed at length in terms of intensified extraction by Srnicek, *Platform Capitalism*, 28, 39–44.

17. Stanislas Dehaene, *Reading in the Brain: The New Science of How We Read* (New York: Viking, 2009), 121. Dehaene explicitly cites Oliver Selfridge's Pandemonium brain model and Donald Hebb's work, both of which we discuss below.

18. Dehaene, *Reading in the Brain*, 147.

19. Johannes Bruder, *Cognitive Code: Post-Anthropocenic Intelligence and the Infrastructural Brain* (Montreal: McGill–Queen's University Press, 2020); Melissa Gregg, *Counter Productive: Time Management in the Knowledge Economy* (Durham, NC: Duke University Press, 2018).

20. On the more general role of "waste" in contemporary biomedicine, see Catherine Waldby and Robert Mitchell, *Tissue Economies: Blood, Organs, and Cell Lines in Late Capitalism* (Durham, NC: Duke University Press, 2006); on the specific biobank

examples discussed here, see Robert Mitchell and Catherine Waldby, "National Biobanks: Clinical Labour, Risk Production, and the Creation of Biovalue," *Science, Technology, and Human Values* 35, no. 3 (2010): 330–355; and Robert Mitchell, "U.S. Biobanking Strategies and Biomedical Immaterial Labor," *Biosocieties* 7, no. 3 (2012): 224–244.

21. A key element of the global order established after World War II was the linkage of oil prices to the price of the US dollar. Petrodollars had been a major source of global management, particularly in nations that were decolonizing and attempting to create autonomous economies. The surfeit of dollars played into a system that assumed that these dollars could be leveraged for energy and infrastructure development projects. Economically poorer countries were expected to take loans in US dollars in order to fund energy and resource development. The collapse of the link between dollars and oil meant that existing loans became increasingly costly (i.e., interest payments suddenly cost more in local currencies), often to the point of being impossible to pay, along with the extreme rise in costs of production and transport of goods. Despite the assumption that nations can always tax and therefore never need to default on debt, the reality proved otherwise, and massive debt default became a possibility. See Benjamin Lee and Edward LiPuma, *Financial Derivatives and the Globalization of Risk* (Durham, NC: Duke University Press, 2004).

22. Lee and LiPuma, *Financial Derivatives and the Globalization of Risk*. For more on systemic risk, see Allan R. Waldman, "OTC Derivatives and Systemic Risk: Innovative Finance or the Dance into the Abyss?," *American University Law Review* 43 (1994): 1023–1090; and Jean-Pierre Zigrand, "Systems and Systemic Risk in Finance and Economics" (SRC Special Paper, no. 1, London School of Economics and Political Science, 2014), http://eprints.lse.ac.uk/61220/1/sp-1_0.pdf.

23. Contemporary measures of GNP, GDP, and growth are all evidence of ongoing faith that growth is natural and that markets organize and provide stability to societies. Within this epistemology the idea that volatility and inefficiency are integral to market operations is anathema. For a discussion of responses to the currency situation and late 1960s volatility in markets, see Philip Mirowski, "Twelve Theses Concerning the History of Postwar Neoclassical Price Theory," *History of Political Economy* 38 (2006): 344–379, esp. 356.

24. Milton Friedman, "The Need for Futures Markets in Currencies," *Cato Journal* 31, no. 3 (2011): 635–641, 637. As MacKenzie notes, Friedman was compensated for writing this article by Leo Melamed, who was setting up an options exchange in Chicago and wanted Friedman's endorsement of such markets (*An Engine, Not a Camera*, 147).

25. Perry Mehrling, *Fischer Black and the Revolutionary Idea of Finance* (2005; repr., New York: John Wiley and Sons, 2012), 36.

26. Examples of the postwar period reworking of "reason" into algorithmic rationality include Herbert Simon, "A Behavioral Model of Rational Choice," *Quarterly Journal of Economics* 69, no. 1 (1955): 99–118; and Warren McCulloch, *Embodiments of Mind* (1965; repr., Cambridge, MA: MIT Press, 1970). For an account of these developments, see Paul Erickson et al., *How Reason Almost Lost Its Mind: The Strange Career of Cold War Rationality* (Chicago: University of Chicago Press, 2013).

27. Mehrling, *Fischer Black*, 20.

28. John von Neumann and Oskar Morgenstern, *Theory of Games and Economic Behavior*, 3rd ed. (Princeton, NJ: Princeton University Press, 1990), 8–9.

29. Lorraine Daston, "The Rule of Rules, or How Reason Became Rationality" (lecture, Max Planck Institute for the History of Science, November 21, 2010), Kindle.

30. Philip Mirowski, "Hell Is Truth Seen Too Late," *Boundary* 46, no. 1 (2019): 1–53, 3.

31. Kenneth Joseph Arrow, *Social Choice and Individual Values* (New York: Wiley, 1963), 1.

32. Arrow, *Social Choice and Individual Values*, 12.

33. There is not, to our knowledge, any critical history of optimization, and existing historical sketches written by mathematicians and economists tend to position optimization as a biological drive or natural force that received proper mathematical formulation in the eighteenth century and was more fully developed in the post–World War II period. See, for example, Ding-Zhu Du, Panos M. Pardalos, and Weili Wu, "History of Optimization," in *Encyclopedia of Optimization*, ed. Christodoulos A. Floudas and Panos M. Pardalos (New York: Springer, 2008). For a critical and nuanced account of optimization theory in economics, see Phillip Mirowski, *More Heat than Light: Economics as Social Physics; Physics as Nature's Economics* (Cambridge: Cambridge University Press, 1989); and Mirowski, *Machine Dreams*. For a discussion of optimization strategies in logistics, see Jesse LeCavalier, *The Rule of Logistics: Walmart and the Architecture of Fulfillment* (Minneapolis: University of Minnesota, 2016). As a few notes toward a future critical history of optimization, it seems that while the term "optimization" was used as early as the mid-nineteenth century, it did not—at least according to Google Ngram—enter common parlance until the 1950s. Google Ngram Viewer, s.v. "optimization," accessed November 4, 2016, https://books.google.com/ngrams/graph?content=optimization&year_start=1800&year_end=2000&corpus=15&smoothing=3&share=&direct_url=t1%3B%2Coptimization%3B%2Cc0. A full-text search of the Institute of Electrical and Electronics Engineers Xplore Digital Library for the term "optimization" between 1890 and 1960 reveals no use of this term before 1904. There is an uptick of uses in the 1920s in articles that appear in the *Proceedings of the Institute of Radio Engineers* and then an explosion of uses in the late 1940s and 1950s, at which point the term also begins to appear in the titles of articles.

34. See, for example, William Aspray, *John von Neumann and the Origins of Modern Computing* (Cambridge, MA: MIT Press, 1990); John von Neumann, "The General and Logical Theory of Automata," in *Papers of John von Neumann on Computing and Computer Theory*, ed. William Aspray (Cambridge, MA: MIT Press, 1986); William Poundstone, *Prisoner's Dilemma* (New York: Doubleday, 1992).

35. Donald Hebb, *The Organization of Behavior: A Neuropsychological Theory* (New York: Wiley, 1949), 10–14.

36. Or, as Hebb put it, "The persistence or repetition of a reverberatory activity (or 'trace') tends to induce lasting cellular changes that add to its stability. . . . When an axon of cell *A* is near enough to excite a cell *B* and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both

cells such that *A*'s efficiency, as one of the cells firing *B*, is increased" (*The Organization of Behavior*, 62).

37. According to Hebb's graduate student Woodburn Heron, the study sought to investigate the future of work conditions and, specifically, the monotony of semi- and even fully automated environments in which humans would spend hours simply overseeing machines. It was assumed that this would result in acute boredom, which would in turn lead to attention, depression, and satisfaction problems. See Woodburn Heron, "The Pathology of Boredom," *Scientific American* 196, no. 1 (January 1957): 52–57, 52–53. The study offered $20 CAD/day ($215.00 in today's US dollars) to lie in bed and do nothing. This was a huge sum, and students joked that they would lie there for a week and then could afford to go on vacation or not have to work for the rest of the year. However, most of the students lasted no more than two or three days. During the study, some individuals began having hallucinations, and cognitive functioning was often impaired. Meghan Crist, "Postcards from the Edge of Consciousness," *Nautilus*, no. 27 (August 6, 2015), http://nautil.us/issue/27/dark-matter/postcards-from-the-edge-of-consciousness-rp.

38. Simon, "A Behavioral Model of Rational Choice," 99.

39. Simon, "A Behavioral Model of Rational Choice"; see also Hunter Crowther-Heyck, *Herbert A. Simon: The Bounds of Reason in Modern America* (Baltimore: Johns Hopkins University Press, 2005); and Crowther-Heyck, *Economics, Bounded Rationality and the Cognitive Revolution* (Brookfield, VT: Edward Elgar, 1992).

40. Herbert A. Simon, *The Sciences of the Artificial* (Cambridge, MA: MIT Press, 1996), 6–7, 14, 24; for a critical contextualization of Simon's figure of the ant, see Jussi Parikka, *Insect Media* (Minneapolis: University of Minnesota Press, 2010), 135.

41. Herbert Simon, "Rational Decision Making," *American Economic Review* 69, no. 4 (1979): 493–513, 493.

42. See Lily E. Kay, "From Logical Neurons to Poetic Embodiments of Mind: Warren Mcculloch's Project in Neuroscience," *Science in Context* 14, no. 4 (2001): 591–614; and Mirowski, *Machine Dreams*, 32.

43. Our argument is not that Hebb or Simon directly influenced Black, Scholes, or Merton but rather that Hebb and Simon—along with Rosenblatt, Hayek, ecologist C. S. Holling (see chapter 4), and many other authors—helped to create a general epistemology that implicitly ratified Black's understanding of markets as noisy, which was in turn related to a more general project of developing tools for locating value in environments that could only ever be partially known. With that said, there were in fact multiple connections among Hebb, Simon, and Black: Simon, for example, was well aware of Hebb's work (see Simon's "Information-Processing Explanations of Understanding," in *The Nature of Thought: Essays in Honor of D. O. Hebb*, ed. Peter W. Jusczyk and Raymond M. Klein [Hillsdale, NJ: Lawrence Erlbaum, 1980]), and Black had intended to complete his PhD with Simon, though that did not work out; see Mehrling, *Fischer Black*, 36 (though Mehrling incorrectly identifies Simon as "Henry Simon").

44. MacKenzie, *An Engine, Not a Camera*, 123, 38.

45. Cited in Duncan Foley, "The Strange History of the Economic Agent" (paper presented to the General Seminar of the Graduate Faculty, New School University, New York, December 6, 2002), https://www.researchgate.net/publication/228563317_The_strange_history_of_the_economic_agent#:~:text=The%20curious%20history%20of%20the,spread%20of%20capitalist%20social%20relations.&text=It%20turns%20out%2C%20as%20well,such%20as%20physics%20and%20biology.

46. Simon, *The Sciences of the Artificial*.

47. Claudia Mareis, "Brainstorming Revisited: On Instrumental Creativity and Human Productivity in the Mid-twentieth Century," *Cultural Politics* 16, no. 1 (2020): 50–69; Horst W. J. Rittel and Melvin M. Webber, "Dilemmas in a General Theory of Planning," *Policy Sciences* 4 (1973): 155–169.

48. Orit Halpern led a research studio course organized in August 2017 through Concordia University in Montreal with Pierre-Louis Patoin from Sorbonne Nouvelle 3. This material is taken from visits to Canadian Malartic between August 2–5, 2017. Dr. Mostafa Benzaazoua, a mine reclamation expert from the Research Institute in Mining and Environment at the University of Quebec at Abitibi, was our guide and collaborator. We are grateful to his assistance and that of his colleagues in doing this research. On August 4, 2017, we were given a tour by the mine staff, whose names are being withheld as a matter of privacy.

49. The Canadian Malartic gold mine in Abitibi, Quebec, is among the largest gold mines in the world. It is certainly the largest operating in Canada and one of the largest open pits in a nation known for mining and extraction. Over half of the world's publicly listed mining and exploration companies are listed as Canadian. Mining in 2018 composed 5 percent of the nominal GDP of the nation, employed some 626,000 individuals, and was valued at CAD $260 billion . These operations are not local, as over two-thirds of the value of Canadian mining assets are located abroad, predominantly in Africa and the Americas (the United States, Mexico, and South America). Canadian Malartic gold mine staff, interviews by Orit Halpern, August 4, 2017; Canadian Malartic Partnership, accessed December 7, 2020, https://canadianmalartic.com/en/.

50. Canadian Malartic gold mine staff, interviews.

51. These changes facilitate the expansion of the mine into deeper zones without using human labor and facilitate the construction of short interval control systems that permit all moving parts and personnel to be tracked. At this point the mine is the deepest in North America, currently dug to 3.1 kilometers underground, with hopes that automation and artificial intelligence can extend this to 3.5 kilometers underground. At such distances and depths, danger from earthquakes and earthly disruptions is sizable. Real-time analytics, improved ability to scan and map instabilities in the rock wall, and constant sensing infrastructures aim to mitigate the hazards of such terraforming projects. At the forefront of these smart mining initiatives are companies such as Cisco Systems and SAP, which are also associated with smartness in many other contemporary areas. See Joel Barde, "Canadian Mining Companies Look to 'Test Mines' to Develop New Technology," *CIM Magazine*, October 25, 2018, https://magazine.cim

.org/en/technology/a-digital-playground-en/; SAP Mining, accessed July 27, 2020, https://www.sap.com/canada/industries/mining.html.

52. Government of Canada, "Gold Facts," accessed July 29, 2020, https://www.nrcan.gc.ca/our-natural-resources/minerals-mining/gold-facts/20514.

53. By 2002, oil markets were already the second-largest futures market and one of the largest derivatives markets across the global exchanges. See Energy Information Administration, US Department of Energy, *Derivatives and Risk Management in the Petroleum, Natural Gas, and Electricity Industries*, October 2002, http://econometricainc.com/wp-content/uploads/2016/08/EIA_Derivatives_Report.pdf.

54. While it is unclear if this number is correct, it is what the engineers on site believed and repeated regularly.

55. The difficulty in pricing metals (and oil) as a result of derivatives markets has led Agnico Eagle to advertise that they do not sell futures. While the mine may "guarantee" the price of its gold, however, the owners of the gold clearly do not, as evidenced by the size of gold derivative and futures markets. Agnico Eagle, "60 Years in the Making," accessed December 7, 2020, https://www.agnicoeagle.com/English/60th-anniversary/default.aspx; Canadian Malartic Partnership, "About Us," accessed December 7, 2020, http://www.canadianmalartic.com/Apropos-partenariat-en.html.

56. Neil Brenner, "Debating Planetary Urbanization: For an Engaged Pluralism," *Environment and Planning D: Society and Space* 36, no. 3 (2018): 1–21.

57. Wikipedia, s.v. "Toronto Stock Exchange," accessed July 29, 2020, https://en.wikipedia.org/wiki/Toronto_Stock_Exchange.

58. City of Toronto, "Innovate Here," accessed August 9, 2020, https://www.toronto.ca/business-economy/invest-in-toronto/innovate-here/.

59. Lee and LiPuma, *Financial Derivatives and the Globalization of Risk*, 80–81.

60. See, for example, Philip Mirowski, *Machine Dreams: Economics Becomes a Cyborg Science* (New York: Cambridge University Press, 2002); and MacKenzie, *An Engine, Not a Camera*.

61. Luke Munn, "From the Black Atlantic to Black-Scholes: Precursors of Spatial Capitalization," *Cultural Politics* 16, no. 1 (2020): 92. Additional accounts of the relationships among insurance, debt, and race include Ian Baucom, *Specters of the Atlantic: A Philosophy of History* (Durham, NC: Duke University Press, 2005); Paula Chakravartty and Denise Ferreira da Silva, eds., *Race, Empire, and the Crisis of the Subprime* (Baltimore: Johns Hopkins University Press, 2013); Calvin Schermerhorn, *The Business of Slavery and the Rise of American Capitalism, 1815–1860* (New Haven, CT: Yale University Press, 2015); Sven Beckert, *Empire of Cotton: A Global History* (New York: Vintage Books, 2015); and Kara Keeling, *Queer Times, Black Futures* (New York: New York University Press, 2019).

62. As Lorraine Daston has noted in *Classical Probability in the Enlightenment*, eighteenth-century insurers shifted from the earlier practices of basing risk calculations on individual guesswork, sentiment, and personal relationships to using

tables, such as the one above, that enabled the automation and standardization of calculation. These latter capacities also permitted the expansion of empire and its goal of administering populations into the future.

63. While both insurance and options involve risk and both can be used to hedge bets, the two techniques are generally distinguished by the criterion that insurance only pays off in the result of the *loss* of the underlying asset (e.g., the sinking of a ship), while an option can result in profit whether the underlying asset (e.g., a company stock) goes up or down in value.

64. Munn, "From the Black Atlantic to Black-Scholes," 103.

65. Munn, "From the Black Atlantic to Black-Scholes," 105.

66. To return to our discussion in chapter 2 of urban zoning, the early twentieth-century zoning distinction between single-family housing (i.e., stand-alone houses, which were generally purchased by the inhabitant) and multifamily housing (i.e., apartment housing, which was generally rented by occupants) was itself a subtle way of enforcing racial hierarchies; see Sonia A. Hirt, "Split Apart: How Regulations Designated Populations to Different Parts of the City," in *One Hundred Years of Zoning and the Future of Cities*, ed. Amnon Lehavi (Cham, Switzerland: Springer, 2018), 3–26.

67. FICO is shorthand for a score calculated by Fair, Isaac, and Company. As Martha Poon notes, the "original Fair Isaac scorecards were custom crafted algorithmic tools designed to capture patterns of default in firm-level consumer credit data" (658n11). See Poon, "From New Deal Institutions to Capital Markets: Commercial Consumer Risk Scores and the Making of Subprime Mortgage Finance," *Accounting, Organizations and Society* 34 (2009): 654–674.

68. As Poon notes, "FICO scores can therefore be said to have reconfigured mortgage markets, putting into place a space of potential high-risk investment action. The intriguing plot twist is that these scores were introduced into the mortgage industry by risk-averse government agencies. When the GSEs adopted the FICO they interpreted scores conservatively, assuming they could be used to reinforce the binary spirit of the traditional form of credit control-by-screening. But because the tool had inscribed within it the possibility of making financially meaningful risk management calculations, it enabled the rise of a new form of financial activity: credit control-by-risk" ("From New Deal Institutions to Capital Markets," 670).

69. Aaron Glantz, *Homewreckers: How a Gang of Wall Street Kingpins, Hedge Fund Magnates, Crooked Banks, and Vulture Capitalists Suckered Millions out of Their Homes and Demolished the American Dream* (New York: HarperCollins, 2019).

70. Baucom, *Specters of the Atlantic*.

71. Keeling, *Queer Times, Black Futures*.

72. On minerals and metals markets, see Martîn Arboleda, *Planetary Mine: Territories of Extraction under Late Capitalism* (New York: Verso, 2020). On energy markets, see Rusian Hharlamov and Heriner Glassbeck, "When Commodities Get Hooked on Derivatives," *Financial Times*, June 13, 2019, https://www.ft.com/content/896e47c8-8875-11e9-a028-86cea8523dc2.

73. Greenpeace, *It's the Finance Sector, Stupid*, January 21, 2020, https://www.greenpeace.org/static/planet4-international-stateless/2020/01/13e3c75b-greenpeace_report_wef_2020_its-the-finance_sector_stupid.pdf.

74. Swiss Re, "Protecting Coral Reefs against Hurricane Damage," *2018 Corporate Responsibility Report*, 2018, https://reports.swissre.com/corporate-responsibility-report/2018/cr-report/solutions/strengthening-risk-resilience-2018-highlights/protecting-coral-reefs-against-hurricane-damage.html; Swiss Re, "Designing a New Type of Insurance to Protect the Coral Reefs, Economies and the Planet," news release, December 10, 2019, https://www.swissre.com/our-business/public-sector-solutions/thought-leadership/new-type-of-insurance-to-protect-coral-reefs-economies.html. See also Catrin Einhorn and Christopher Flavelle, "A Race against Time to Rescue a Reef from Climate Change," *New York Times*, December 5, 2020, https://www.nytimes.com/2020/12/05/climate/Mexico-reef-climate-change.html.

75. Swiss Re, "Designing a New Type of Insurance."

76. For examples of the default critical account of finance, see Stephen Graham and Simon Marvin, *Splintering Urbanism: Networked Infrastructures, Technological Mobilities and the Urban Condition* (London: Routledge, 2001) (discussed in chapter 2), and most critical literature on smart cities.

77. Christopher Flavelle, "A Climate Plan in Texas Focuses on Minorities. Not Everyone Likes It," *New York Times*, July 24, 2020, https://www.nytimes.com/2020/07/24/climate/houston-flooding-race.html. For discussion about rethinking publics, politics, infrastructures, and finance, see Stephen J. Collier, James Christopher Mizes, and Antina von Schnitzler, "Preface: Public Infrastructures/Infrastructural Publics," *Limn*, no. 7 (2016), https://limn.it/issues/public-infrastructuresinfrastructural-publics/.

78. James Christopher Mizes, "Who Owns Africa's Infrastructure?," *Limn*, no. 7 (2016), https://limn.it/issues/public-infrastructuresinfrastructural-publics/.

79. Janet Roitman, "Africa Rising: Class or Finance," podcast, University of Helsinki Seminar, 117 min., April 12, 2020, https://blogs.helsinki.fi/anthropology/2020/12/04/janet-roitman-africa-rising-class-or-finance/.

80. Alexandra Ocasio-Cortez, H. Res. 109: Recognizing the Duty of the Federal Government to Create a Green New Deal (2019). We also take up these questions in our excursus on electrical grids in chapter 2.

81. Kenneth Boulding, "The Economics of the Coming Spaceship Earth," in *Environmental Quality in a Growing Economy*, ed. H. Jarrett (Baltimore: Resources for the Future/Johns Hopkins University Press, 1966), 3–14.

82. Martin, "What Difference Do Derivatives Make?," 189–210.

CHAPTER 4

1. Centers for Disease Control and Prevention, *Interim Pre-pandemic Planning Guidance: Community Strategy for Pandemic Influenza Mitigation in the United States—Early, Targeted, Layered Use of Nonpharmaceutical Interventions*, February 2007, https://www.cdc.gov/flu/pandemic-resources/pdf/community_mitigation-sm.pdf. According to news reports,

no one can remember who precisely wrote this report; see Mark Wilson, "The Story behind 'Flatten the Curve,' the Defining Chart of the Coronavirus," *Fast Company*, March 3, 2020, https://www.fastcompany.com/90476143/the-story-behind-flatten-the-curve-the-defining-chart-of-the-coronavirus. There are, of course, precedents for this basic approach: in the 1918 flu pandemic, infection rates in different urban areas were compared, and in the United States during World War II, similar charts demonstrated how rationing would save materials and energy for the military. We are sure there are many other examples of such precedents.

2. Lisa Parks and Janet Walker, "Disaster Media: Bending the Curve of Ecological Disruption and Moving toward Social Justice," *Media+Environment* 2, no. 1 (2020), https://mediaenviron.org/article/13474-disaster-media-bending-the-curve-of-ecological-disruption-and-moving-toward-social-justice.

3. "J. Robert Oppenheimer, Atom Bomb Pioneer, Dies," *New York Times*, February 19, 1967, https://archive.nytimes.com/www.nytimes.com/learning/general/onthisday/bday/0422.html.

4. Victor Papanek, *Design for the Real World: Human Ecology and Social Change*, 2nd ed. (Chicago: Academy Chicago Publishers, 1985), 220.

5. See the references to Neutra's work in chapter 3.

6. Quoted in Elizabeth M. DeLoughrey, "The Myth of Isolates: Ecosystem Ecologies in the Nuclear Pacific," *Cultural Geographies* 20, no. 2 (2012): 177. To this day, the Marshall Islanders continue to suffer uncompensated damage to their lives and health from the high mutation rates and ongoing cancer spawned from these tests.

7. DeLoughrey, "The Myth of Isolates." See also Richard H. Grove, *Green Imperialism: Colonial Expansion, Tropical Island Edens and the Origins of Environmentalism, 1600–1860* (Cambridge: Cambridge University Press, 1996).

8. Joel B. Hagen, *An Entangled Bank: The Origins of Ecosystem Ecology* (New Brunswick, NJ: Rutgers University Press, 1992), 55–62, 64–68.

9. Hagen, *An Entangled Bank*, 65.

10. Peder Anker, *Imperial Ecology: Environmental Order in the British Empire, 1895–1945* (Cambridge, MA: Harvard University Press, 2001), 31.

11. Anker, *Imperial Ecology*.

12. Howard T. Odum and Eugene P. Odum, "Trophic Structure and Productivity of a Windward Coral Reef Community on Enitwetok Atoll," *Ecological Monographs* 25 (July 1955): 291.

13. Laura J. Martin, "The X-ray Images That Showed Midcentury Scientists How Radiation Affects an Ecosystem," *Slate*, December 28, 2015, https://slate.com/human-interest/2015/12/how-midcentury-ecologists-used-x-ray-radioautographs-to-see-how-radiation-moves-through-bodies.html.

14. Odum apparently attended the conferences once as well but thought they were a waste of time (Hagen, *An Entangled Bank*, 213). However, he is also considered by many historians and documentarists, including Adam Curtis (*All Watched Over by Machines of Loving Grace*, BBC Films, 2011) and Peter J. Taylor, as being central to

introducing cybernetic concepts and postwar approaches to systems, feedback and self-regulation, and organization into ecology. See Peter J. Taylor, *Unruly Complexity: Ecology, Interpretation, Engagement* (Chicago: University of Chicago Press, 2010).

15. G. E. Hutchinson, "Circular Causal Systems in Ecology," *Annals of the New York Academy of Science* 40 (1948): 221–246; for context, see Brian Lindseth, "The Pre-history of Resilience in Ecological Research," *Limn*, no. 1 (2011), https://limn.it/articles/the-pre-history-of-resilience-in-ecological-research/.

16. Peter J. Taylor, "Technocratic Optimism, H.T. Odum, and the Partial Transformation of Ecological Metaphor after World War II," *Journal of the History of Biology* 21 (1988): 217.

17. Howard T. Odum, *Systems Ecology: An Introduction*, ed. Robert L. Metcalf and Werner Stumm (New York: John Wiley and Sons, 1983), ix–x.

18. His brother Eugene summed up this approach in his foundational text to the field, *Ecology* (New York: Holt, Rinehart, and Winston, 1963, repr. 1975): "A very important corollary . . . is the principle of hierarchical control. Simply stated, this principle is as follows: As components combine to produce larger functional wholes in a hierarchical series, new properties emerge . . . to understand and properly manage a forest we must not only be knowledgeable about trees as populations, but we must also study the forest as an ecosystem" (5).

19. On the importance of Lotka for both Hutchison and Odum, see Taylor, "Technocratic Optimism," 217, 219, 225–226. On the differences between Lotka's and Mayr's approaches to animal populations, see Philip Kreager, "Darwin and Lotka: Two Concepts of Population," *Demographic Research* 21, no. 2 (2009): 469–502.

20. Taylor, "Technocratic Optimism."

21. For more on this, see Orit Halpern, *Beautiful Data: A History of Vision and Reason since 1945* (Durham, NC: Duke University Press, 2015); and Halpern, "Dreams for Our Perceptual Present: Temporality, Storage, and Interactivity in Cybernetics," *Configurations* 13, no. 2 (2005): 283–319; see also Paul N. Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge, MA: MIT Press, 1996).

22. See E. Odum, *Ecology*, 7–8, 152.

23. "Agent Orange," History Channel, May 16, 2019, https://www.history.com/topics/vietnam-war/agent-orange-1. See also Jacob Darwin Hamblin, *Arming Mother Nature: The Birth of Catastrophic Environmentalism* (Oxford: Oxford University Press, 2013).

24. Donella H. Meadows et al., *The Limits to Growth: A Report for the Club of Rome's Project on the Predicament of Mankind* (New York: Universe Books, 1972), esp. 1–54.

25. The Volkswagen Foundation gave USD $250,000, and a group was assembled at MIT to prepare a comprehensive model. Five sectors were chosen—demography, economics, geology, ecology, and agriculture—and each area was studied and the findings added to the basic model structure from Forrester. In 1971 the Club of Rome conceived that this research should become a report, *The Limits to Growth*.

See Fernando Elichirigoity, *Planet Management: Limits to Growth, Computer Simulation, and the Emergence of Global Spaces* (Evanston, IL: Northwestern University Press, 1999).

26. As Elichirigoity notes in *Planet Management*, Forrester himself did not end up personally leading the *Limits to Growth* team, as some of the study's funders had expected, because Forrester had already committed himself to another project of computationally modeling a national economy (95).

27. Donella H. Meadows, "The History and Conclusions of *Limits to Growth*," *System Dynamics Review* 23 (2007): 191–197, 193.

28. Elichirigoity, *Planet Management*, 66, 78–77.

29. For a helpful history of the "closing" of the world in this way, see Edwards, *The Closed World*.

30. See Arturo Escobar, *Encountering Development: The Making and Unmaking of the Third World*, 2nd ed. (Princeton, NJ: Princeton University Press, 2012); Michelle Murphy, *Seizing the Means of Reproduction* (Durham, NC: Duke University Press, 2012); Thomas Robertson, "'This Is the American Earth': American Empire, the Cold War, and American Environmentalism," *Diplomatic History* 32, no. 4 (2008): 561–584.

31. On the emergence in the 1950s of economic "growth" as an agreed-upon international goal of Western democratic countries, see Scott O'Bryan, *The Growth Idea: Purpose and Prosperity in Postwar Japan* (Honolulu: University of Hawaiʻi Press, 2009), 133–171; Robert M. Collins, *More: The Politics of Economic Growth in Postwar America* (Oxford: Oxford University Press, 2000), 17–39; David W. Ellwood, *Rebuilding Europe: Western Europe, America, and Postwar Reconstruction* (London: Longman, 1992), 205–241; and Matthias Schmelzer, *The Hegemony of Growth: The OECD and the Making of the Economic Growth Paradigm* (Cambridge: Cambridge University Press, 2016), esp. 142–162. As Schmelzer notes, one important impetus for this emphasis on growth was the perception that the economies of the USSR and its allies were expanding at a rate of 10–15 percent per year (151).

32. Friedrich Hayek, "The Pretence of Knowledge" (lecture, Sveriges Riksbank Prize in Economic Sciences in Memory of Alfred Nobel, December 11, 1974), https://www.nobelprize.org/prizes/economic-sciences/1974/hayek/lecture/.

33. Hayek, "The Pretence of Knowledge."

34. Milton Friedman, "The Need for Futures Markets in Currencies," *Cato Journal* 31, no. 3 (2011): 635–641, 636. This article is a reprint of a December 20, 1971, report to the Chicago Mercantile Exchange, and as Donald MacKenzie documents, this was an "article for hire," as the head of the Chicago Mercantile Exchange paid Friedman to write the article, which was intended to (and did) pave the way for federal approval of precisely such a market. Hence, the article advocates not only for a futures currency market but for its location in the United States. Friedman contended that "as Britain has demonstrated in the nineteenth century, financial services of all kinds can be a highly profitable export commodity," and he proposed that a US-based futures market would strengthen the American position while also maintaining the stability and expansion of global trade.

35. Friedman, "The Need for Futures Markets," 637. Friedman stressed that this market "cannot depend solely on hedging transactions by persons involved in foreign trade and investment." In addition, he said that the "market needs speculators who are willing to take open positions as well as hedges. The larger the volume of speculative activity, the better the market and the easier it will be for persons involved in foreign trade and investment to hedge at low costs and at market prices that move only gradually and are not significantly affected by even a large commercial transactions" (638). The terminology of resilience seems not to have been Friedman's innovation, as other economists had also used this term in the late 1960s when discussing the need for Bretton Woods reform.

36. Jeremy Walker and Melinda Cooper also connect Holling and Hayek in "Genealogies of Resilience: From Systems Ecology to the Political Economy of Crisis Adaptation," *Security Dialogue* 14, no. 2 (2011): 143–160, and we draw on some of their analysis here.

37. C. S. Holling, "Resilience and Stability of Ecological Systems," *Annual Review of Ecological Systems* 4 (1973): 1–23, 1.

38. Peter Larkin, *The Canadian Encyclopedia*, s.v. "Crawford Stanley Holling," last modified July 11, 2020, https://thecanadianencyclopedia.ca/en/article/crawford-stanley-holling.

39. C. S. Holling, "The Spruce Budworm/Forest Management Problem," in *Adaptive Environmental Assessment and Management*, ed. C. S. Holling (New York: John Wiley and Sons, 1978), 143–183.

40. For a summary of strategies in adaptive management, see Holling, *Adaptive Environmental Assessment and Management*. The emphasis of Holling and his coauthors in *Adaptive Environmental Assessment and Management* on small teams and regional (vs. global) projects was presumably also intended as a critique of the "big science" approach that characterized the International Biological Program (IBP; 1964–1974), one part of which was headed by Howard Odum. On big science and the IBP, see Hagen, *An Entangled Bank*, 165–189.

41. Holling, "Resilience and Stability of Ecological Systems," 21. Holling in fact distinguished between two kinds of resilience: "engineering resilience" and "ecological resilience." Engineering resilience is mechanical and incapable of rapid evolutionary change, and, within ecology, its practices are indebted to ideas of perfectly recording the world, counting populations, and assuming that the future can be predicted directly from past data. Ecological resilience contests each of these premises. See especially Holling's essay "Engineering Resilience versus Ecological Resilience," in *Engineering within Ecological Constraints*, ed. Peter C. Schulze (Washington, DC: National Academies Press, 1996), 31–44, reprinted in Lance H. Gunderson, Craig R. Allen, and C. S. Holling, eds., *Foundations of Ecological Resilience* (Washington, DC: Island Press, 2009), 51–66.

42. For a summary of strategies in adaptive management, see Holling, *Adaptive Environmental Assessment and Management*.

43. Holling, "Resilience and Stability of Ecological Systems," 21.

44. Holling, *Adaptive Environmental Assessment and Management*, 9.

45. This observation of Gaia is inspired by Melinda Cooper, *Life as Surplus* (Seattle: University of Washington Press, 2008), 35.

46. Burton G. Malkiel and Eugene F. Fama, "Efficient Capital Markets: A Review of Theory and Empirical Work," *Journal of Finance* 25, no. 2 (1970): 383–417.

47. We might also add those social theorists and historians who introduced models of abrupt shifts of either paradigms (Thomas Kuhn) or epistemes (Michel Foucault).

48. Or, as Holling and his coauthors put it, "Human systems have the same four properties (namely, organized connection between parts, spatial heterogeneity, resilience, and dynamic variability) that ecological systems have" (35–36).

49. See the work by Holling and others on a panarchy model of ecology in Lance H. Gunderson and C. S. Holling, eds., *Panarchy: Understanding Transformations in Human and Natural Systems* (Washington, DC: Island Press, 2002).

50. For the many discourses into which Holling-inspired concepts of resilience have spread, see Melinda Cooper and Jeremy Walker, "Genealogies of Resilience: From Systems Ecology to the Political Economy of Crisis Adaptation," *Security Dialogue* 14, no. 2 (2011): 143–160; Andreas Folkers, "Continuity and Catastrophe: Business Continuity Management and the Security of Financial Operations," *Economy and Society* 46, no. 1 (2017): 103–127; Kevin Grove, *Resilience* (New York: Routledge, 2018); David Chandler, "Resilience and Human Security: The Post-Interventionist Paradigm," *Security Dialogue* 43, no. 3 (2012): 213–229; Chandler, *Resilience: The Governance of Complexity* (New York: Routledge, 2014); and Stockholm Resilience Centre, "About Us," Stockholm University, 2020, https://www.stockholmresilience.org/about-us.html. For work by Holling and the Resilience Alliance, see C. S. Holling, *Adaptive Environmental Assessment and Management* (New York: John Wiley and Sons, 1978); "Ontario Completes Sale of 14 Million Shares of Hydro One to Ontario First Nations," *NetNewsLedger*, January 2, 2018.

51. Stockholm Resilience Centre, https://www.stockholmresilience.org/about-us.html.

52. Holling, *Adaptive Environmental Assessment and Management*, 3–4.

53. Holling, *Adaptive Environmental Assessment and Management*, ix–x.

54. Holling, *Adaptive Environmental Assessment and Management*, xi.

55. See, e.g., Holling, *Adaptive Environmental Assessment and Management*, 215–242.

56. For a history of scenario planning within Cold War policy circles and corporations (especially RAND), see Bradfield et al., "The Origins and Evolution of Scenario Techniques in Long Range Business Planning," *Futures* 37 (2005): 795–812. As Bradfield et al. note, Herman Kahn's coauthored *The Year 2000: A Framework for Speculation on the Next Thirty-Three Years* (1967) helped to popularize the concept and practice of planning by means of future "scenarios" (799).

57. Meadows et al., *The Limits to Growth*, 93, 186.

58. Meadows et al., *The Limits to Growth*, 121.

59. See Folkers, "Continuity and Catastrophe," 103–127; Folkers, *Das Sicherheitsdispositiv der Resilienz: Katastrophische Risiken und die Biopolitik vitaler Systeme* (Frankfurt am Main: Campus, 2018).

60. Folkers, "Continuity and Catastrophe," 104–105.

61. Holling uses the phrase "learning with continuity" in "Understanding the Complexity of Economic, Ecological, and Social Systems," *Ecosystems* 4, no. 5 (2001): 390–405, at 390, 399, 402.

62. Goldman Sachs Global Business Continuity Program, *Business Continuity and Technology Resilience Program for Disaster Recovery: Overview*, 2020, accessed December 29, 2020, https://www.goldmansachs.com/disclosures/business-continuity.pdf.

63. See Folkers, "Continuity and Catastrophe"; Stephen Collier and Andrew Lakoff, "Vital Systems Security: Reflexive Biopolitics and the Government of Emergency," *Theory, Culture and Society* 32, no. 3 (2015): 19–51; and Deborah Cowen, *The Deadly Life of Logistics* (Minneapolis: University of Minnesota Press, 2014). For more on the Cold War legacy of securitization and vital systems security, see Joseph Masco, *The Theater of Operations: National Security Affect from the Cold War to the War on Terror* (Durham, NC: Duke University Press, 2014); Stephen Collier and Andrew Lakoff, "Introduction: Systemic Risk," *Limn*, no. 1 (2011). For documents on vital system security policy in the US government and finance, see Barak Obama, the White House, Office of the Press Secretary, *National Security Strategy*, February 6, 2015, https://obamawhitehouse.archives.gov/sites/default/files/docs/2015_national_security_strategy_2.pdf; Goldman Sachs Global Business Continuity Program, *Business Continuity and Technology Resilience Program*.

64. Nassim Taleb, *Antifragile: Things That Gain from Disorder* (New York: Random House, 2012), 67.

65. Taleb, *Antifragile*, 4–5.

66. Debjani Bhattacharyya, *Empire and Ecology in the Bengal Delta: The Making of Calcutta* (Cambridge: Cambridge University Press, 2018), Kindle.

67. Suman Chakraborti, "Data Maturity: New Town Is India's 8th Smartest City," *Times of India*, June 29, 2021, https://timesofindia.indiatimes.com/city/kolkata/data-maturity-new-town-is-indias-8th-smartest-kolkata/articleshow/83943513.cms.

68. Sedeshna Mitra, "Roads to New Urban Futures: Flexible Territorialisation in Peri-urban Kolkata and Hyderbad," *Economic and Political Weekly* 53, no. 49 (2018): 56–64; Srestha Banerjee, "An Evaluation of the Political Economy of Urban Ecological Sustainability in Indian Cities in a Globalizing Era: A Perspective from the East Kolkata Wetlands" (PhD diss., University of Delaware, 2009).

69. While actual information about the financing of the Rajarat development is difficult to find, data about the lack of occupancy and the probable financing came from discussions with the Kolkata Research Group members Ranabir Samadar and Mithelesh Kumar on March 31 and April 1, 2016. For further research on the zone produced by the Transit Labour project, directed by Brett Neilson and Ned Rossiter, see Transit Labour, "Platform: Kolkata," accessed April 8, 2017, http://transitlabour.asia/kolkata/.

70. Sudeshna Banerjee, "The March of the Mega-city: Governance in West Bengal and the Wetlands to the East of Kolkata," *South Asia Chronicle* 2 (2012): 93–118; Patrick Barkham, "The Miracle of Kolkata's Wetlands—and One Man's Struggle to Save Them," *Guardian*, March 9, 2016; Sana Huque, Sarmistha Pattanaik, and D. Parthasarathy, "Cityscape Transformation and the Temporal Metamorphosis of East Kolkata Wetlands: A Political Ecology Perspective," *Sociological Bulletin* 69, no. 1 (2020): 102–103.

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72. Ministry of Urban Development, Government of India, *Smart Cities: Mission Statement and Guidelines*, June 2015, http://smartcityrajkot.in/Docs/SmartCityGuidelines.pdf.

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74. Paul Virilio, *Speed and Politics* (Cambridge, MA: MIT Press, 2006).

75. See, for example, the *New York Times* series on resilience in the COVID-19 era, May 3, 2021, https://www.nytimes.com/spotlight/resilience.

76. This is also another example of that weaponization of scientific uncertainty called "agnatology" by historians of science Robert Proctor and Naomi Oreske and that is characteristic of the business strategies of what Oreske calls "merchants of doubt." Proctor and Oreske documented the deliberate use, and cultivation, of scientific uncertainty by tobacco and energy companies as a means of preventing or delaying government regulation, and Philip Mirowski has noted that this strategy is part of a more general neoliberal attack on independent (i.e., noncorporate) scientific knowledge. Within the terms of our chapter, agnatology names methods of profiting from the uncertainty inherent in complex systems, and this project is of course facilitated by the premise that error is intrinsic to every attempt to model that complexity. In the case of COVID-19, the more general strategy of agnatology also resonated with President Trump's authoritarian strategies. Trump's political career was founded on a critique of elitism and scientific forms of evidence and evidence-based decision-making. The early uncertainty within scientific forums about COVID-19 facilitated this critique of experts and science and allowed the Right to transform the catastrophe into a war of ideologies. Within this war of ideologies, Trump could effectively position his authoritarian confidence as the best and most valid voice while simultaneously suggesting that some people should be sacrificed for the economy. See Nicholas B. King, "Briefing: Evidence and Uncertainty during the Covid-19 Pandemic," Max Bell School of Public Policy, McGill University, https://www.mcgill.ca/maxbellschool/article/briefing-evidence-and-uncertainty-during-covid-19-pandemic. David Chandler has also argued that resilience and concepts of complexity have become excuses for government not to interfere in situations of crisis or disaster. Chandler, *Resilience: The Governance of Complexity*.

77. Kara Keeling, *Queer Times, Black Futures* (New York: New York University Press, 2019), 22.

78. Keeling, *Queer Times, Black Futures*, 163.

79. Ferris Jabr, "The Social Life of Forests," *New York Times*, December 12, 2020.

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81. Suzanne W. Simard, "Nature's Internet: How Trees Talk to Each Other in a Healthy Forest," 2017, TEDxSeattle, February 2, 2017, https://www.youtube.com/watch?v=breDQqrkikM.

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83. Elise Filotas et al., "Viewing Forests through the Lens of Complex Systems Science," *Ecosphere* 5, no. 1 (2014): 1–23.

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86. Keeling, *Queer Times, Black Futures*, xiv–xv, 153–155. On the Black radical tradition, see Cedric J. Robinson, *Black Marxism: The Making of the Black Radical Tradition* (1986; repr., Chapel Hill: University of North Carolina Press, 2000); on freedom dreams, see R. D. G. Kelley, *Freedom Dreams: The Black Radical Imagination* (Boston: Beacon Press, 2002).

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1. See, for example, Edward Nik-Khah, "George Stigler, the Graduate School of Business, and the Pillars of the Chicago School," in *Building Chicago Economics: New Perspectives on the History of America's Most Powerful Economics Program*, ed. Robert Van Horn, Philip Mirowski, and Thomas A. Stapleford (Cambridge: Cambridge University Press, 2011), 116–147; Edward Nik-Khah, "The 'Marketplace of Ideas' and the Centrality of Science to Neoliberalism," in *The Routledge Handbook of the Political Economy of Science*, ed. David Tyfield, Rebecca Lave, Samuel Randalls, and Charles Thorpe (London: Routledge, 2017), 31–42; Philip Mirowski, "Hell Is Truth Seen Too Late," *boundary 2* 46, no. 1 (2019): 1–53. See also Wendy Brown, *Undoing the Demos: Neoliberalism's Stealth Revolution* (New York: Zone Books, 2015).

2. See Nik-Khah, "George Stigler" and "The 'Marketplace of Ideas'"; Brown, *Undoing the Demos*.

3. See Carl Schmitt, *The Crisis of Parliamentary Democracy*, trans. Ellen Kennedy (Cambridge, MA: MIT Press, 1985); Leo Strauss, *Natural Right and History* (Chicago: University of Chicago Press, 1953), 6.

4. See Jonathan Mattingly, "Declaration of Jonathan Mattingly," Common Cause, et al. v. League of Women Voters of North Carolina, et al. Civil Action No.

1:16-CV-1026-WO-JEP/Civil Action No. 1:16-Cv-1164-WO=JEP (US District Court for the Middle District of North Carolina, March 6, 2017), https://s10294.pcdn.co/wp-content/uploads/2016/05/Expert-Report-of-Jonathan-Mattingly.pdf.

5. Joseph Dumit, "Circuits in the Mind" (lecture, New York University, 2007).

6. The so-called Caravan of Death carried out the executions of 26 people in Chile's south desert and 71 in the north desert. BBC News, "Chile's Caravan of Death: Ex-Army Chief Cheyre Convicted for Pinochet-Era Crimes," November 10, 2018, https://www.bbc.com/news/world-latin-america-46160437. See also National Commission for Truth and Reconciliation, "Report of the Chilean National Commission on Truth and Reconciliation" (Santiago, 1990), https://web.archive.org/web/20091124213320/http://www.usip.org/resources/truth-commission-chile-90. Orit Halpern wishes to thank Katheryn Detwiler for her research assistance and aid in doing this Chile research. Her dissertation, "Science Fell in Love with the Chilean Sky: Data as a Speculative Resource in the Atacama Desert," explores connections between astronomy and extraction in the Atacama Desert. I am indebted to her labor in helping me gain access to the ALMA Observatory, the Soquimich lithium mine, and the CMM laboratory, and I appreciate the productive discussions ensuing from the research concerning data, time, landscapes, and trauma in this desert.

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