The Environmental History of Computing

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ABSTRACT: From Charles Babbage's Difference Engine (a product of an increasingly global British maritime empire) to Herman Hollerith's tabulating machine (designed to solve the problem of "seeing like a state" in the newly trans-continental American Republic) to the emergence of the modern petrochemical industry, information technologies have always been closely associated with the human desire to understand and manipulate their physical environment. More recently, humankind has started to realize the environmental impacts of information technology, including not only the toxic byproducts associated with their production, but also the polluting effects of the massive amounts of energy and water required by data centers at Google and Facebook (whose physicality is conveniently and deliberately camouflaged behind the disembodied, ethereal "cloud"). This paper grounds the history of information technology in the material world by focusing on the relationship between "computing power" and more traditional processes of resource extraction, exchange, management, and consumption.

Introduction

In the fall of 2011 an Irish-based computer networking company began construction on a new transatlantic communications service that would eventually become known as the Hibernia Express. Laying the 4,600 kilometers of fiber-optic cable that comprise the Express required four years and cost $300 million. The payoff of this massive investment in infrastructure was a seemingly minor ten percent reduction in network latency (a measure of the time required for a data packet to traverse a network round-trip). The intended beneficiaries were high-frequency algorithmic trading firms in New York and London, for whom the six extra millisec-

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onds gained—roughly the amount of time it takes for a honeybee to flap its wings once—would translate into hundreds of millions of dollars annually in competitive advantage.

Although there is certainly an art to building and maintaining a network of thin glass filaments stretching for thousands of kilometers across an ocean floor, the real secret to Hibernia's success was not so much technology as geography: the route that its cables follow across the Atlantic is 500 kilometers shorter than those previously established, and even moving at an approximation to the speed of light, it takes time for information to travel. As a result, innovation in one of the iconically high-tech sectors of the twenty-first-century information economy is dependent on activities that seem decidedly nineteenth-century: hiring and outfitting ships, sailors, and longshoreman; surveying ocean depths and shorelines; stretching, splicing, and rigging cables; constructing physical rather than informational infrastructure. Far from being made irrelevant by global information networks, history and geography defined where and how these networks were conceived and constructed; in turn, access to these networks reinforced the centrality and significance of specific spaces and places (such as London and New York City).[1] In a wide variety of contexts, from finance to gaming to video-on-demand, even relatively small differences in distance translate into meaningful variations in the user experience of information technology.

That material constraints and considerations continue to be relevant in the digital era runs counter to the prevailing spirit of the age. Over the past half century, we (in the Western world, at least) have grown accustomed to thinking of ourselves as living in an information society, by which we also mean a post-industrial society.[2] And although as Ron Kline has elegantly described, the two concepts have separate but related histories, they have come to be seen as largely synonymous.[3] While the sociologist Daniel Bell in *The Coming of the Post-Industrial Society* emphasized economic and structural changes, the implication was that information technologies would soon displace the traditional technologies of industrial modernity—roads and bridges, assembly lines and automobiles, factories and farm equipment—as the focus of future economic activity.[4] It was not a stretch to assume, as James Martin did in his 1978 Pulitzer Prize-nominated *The Wired Society*, that such a shift would lead to a less materially-oriented and environmentally impactful mode of existence.[5] By the time the increasing ubiquity of the Internet made tangible the global information and communications network that Martin had envisioned, the belief that we would

1. Nicole Starosielski, *The Undersea Network*.
2. David Lyon, "From 'Post-Industrialism' to 'Information Society.'"
3. Ronald R. Kline, *The Cybernetics Moment*, 224.
4. Daniel Bell, *The Coming of Post-Industrial Society*.
5. James Martin, *The Wired Society*, 4.

soon be living in a world in which material resources were largely unnecessary had become an article of faith among the technorati.[6] The most influential of these was Nicholas Negroponte, then head of the Media Lab at MIT, whose 1995 bestseller *Being Digital* envisioned a techno-utopian future in which the material (atoms) would be replaced by the virtual (bits). The "rapid exponential shift from atoms to bits" in the digital era was, according to Negroponte, both "inevitable and unstoppable."[7] Shortly thereafter the British economist Diane Coyle would declare the digital economy to be "weightless," both figuratively and literally.[8] In such accounts, the alleged immateriality of the "information superhighway" was often explicitly contrasted with the physicality and resource demands of its industrial era equivalents.[9]

And so it is not surprising that many of us, as citizens of the information society, associate "going digital" with an increasing independence from material limitations. As more and more goods and services shift from brick-and-mortar providers into the invisible realm of Cyberspace, it seems to many that we are moving to a less resource-intensive and environmentally impactful economy. This is particularly true as more of our digital resources relocate to the so-called "Cloud." Many of the informational activities that until very recently required access to multiple specialized devices (televisions, stereo systems, personal computers, and video game consoles) have been consolidated into single, small, mobile devices. The vast material infrastructure that makes it all possible has been deliberately dematerialized and disappeared by technology companies into the ethereal and commodified Cloud.

For many middle-class, white-collar, eco-sensitive Americans, the shift from industrial to post-industrial society seems to be a largely positive development. While the dirty and dangerous work of industrial manufacturing might not have been eliminated entirely, at least it is no longer visible. It happens in other parts of the world, and by (and to) other kinds of people. And where so many of humankind's other great technological accomplishments have been compromised by war, disease, pollution, and other unintended and undesirable consequences, information technology does appear to be clean, safe, and of relatively low impact on the environment. Indeed, the seemingly inexorable march of Moore's Law toward smaller, faster, and more powerful computers serves for many in the Western world the last remaining remnant of our long tradition of technology-driven utopianism.

6. Ursula Huws, "Material World"; Frans Berkhout and Julia Hertin, "De-Materialising and Re-Materialising"; Nancy Katherine Hayles, *How We Became Posthuman*; Jean-François Blanchette, "A Material History of Bits."

7. Nicholas Negroponte, *Being Digital*.

8. Diane Coyle, *The Weightless World*.

9. Alvin Toffler and Heidi Toffler, *Creating a New Civilization*; Kevin Kelly, *New Rules for the New Economy*; Al Gore, *Earth in the Balance*.

If we focus solely on the consumption side of computing and information technology, this model of a radical, discontinuous break with our industrial history does seem plausible. For the most part, we experience only the positive benefits of information technology, in large part because the labor and geography associated with the construction, maintenance, and dismantling our digital devices has been rendered largely invisible.

But when we explore the places where large-scale computation happens, the people who work in those places, and the embeddedness of those sites in specific social and geographical landscapes—that is to say, when we look at the vast web of wires, cables, towers, generators, and other physical equipment that underlies the apparently virtual realm of Cyberspace—the digital present does not seem quite so discontinuous with our industrial past. Collectively speaking, our online activities represent a significant portion of the world's industrial output. If the Cloud were a country it would be the sixth largest consumer of electricity on the planet.[10] A typical data center requires hundreds of thousands of gallons of fresh water a day to operate; a single semiconductor fabrication facility requires millions.[11] The manufacture of both digital devices and renewable energy technologies require the extraction of massive amounts of mineral resources.[12] The "online" retailer Amazon owns and operates one of the largest warehouse, transportation, and logistics operations in the world.[13] A significant percentage of the most powerful supercomputers in existence are devoted to climate modeling.[14] From Bitcoin "mines" to server "farms" to data "warehouses," the places and processes that are used to produce virtual commodities look surprisingly similar to those found in more traditional forms of industrial manufacturing.[15] They can be resource-intensive, pollution-producing, and potentially damaging to the environment.

This paper represents an attempt to develop an environmental history of computing. It is an exploratory effort; one that I hope will stimulate further research and dialogue. I am inspired by work of fellow historians of technology of demonstrated how environmental history can serve as a productive tool for expanding the scope of our field to include new actors, places, and questions.[16] As with all environmental histories of technology, the focus is not only on how technological systems reshape our environment (resource extraction, energy use, e-waste) and how information tech-

10. Gary Cook et al., "Clicking Clean."

11. Mél Hogan, "Data Flows and Water Woes"; Hogan, *The Big Thirst*.

12. Keith Veronese, *Rare*.

13. Jason Del Rey, "Amazon Buys Thousands."

14. Paul N. Edwards, *A Vast Machine*; Michael Feldman, "TOP500 Meanderings."

15. Jussi Parikka, *A Geology of Media*; Nathan Ensmenger and Rebecca Slayton, "Computing and the Environment."

16. Jeffrey K. Stine and Joel A. Tarr, "At the Intersection of Histories," 601; Richard White, *The Organic Machine*; Sara B. Pritchard, *Confluence*; Christopher F. Jones, *Routes of Power*.

nologies alter the way we perceive and understand the material world (via computer simulation and imaging, global positioning systems, and environmental monitoring), but also how environmental factors have shaped the development of these systems and technologies.[17] I am particularly interested in the ways in which focusing the material underpinnings of the digital economy—in other words, by the relationship between "computing power" and more traditional processes of resource extraction, exchange, management, and consumption—we can tell a more global and inclusive history of computing that encompasses unconventional and heretofore neglected participants in the digital economy.[18]

Seeing Like a Computer

One of the most widely-read histories of technology published in the past several decades tells the tale of the eighteenth-century clock-maker John Harrison, who according to book's self-description, was the "Lone Genius Who Solved the Greatest Scientific Problem of His Time."[19] The scientific problem in question was the determination of longitude, and the solution was the invention of an accurate chronometer. What was at stake was the ability of the British Empire to effectively manage and protect its growing fleet of military and commercial vessels, a fleet that would ultimately allow this tiny island nation to control over one-quarter of the land mass of the entire planet.

In Dava Sobel's heroic narrative, the working-class, self-educated Harrison triumphs against all odds over the entrenched interests of the scientific and political establishment, as embodied in the figure of Nevil Maskelyne, the Astronomer Royal. But as Mary Croarken writes in her less celebrated but more balanced history, it was in fact Maskelyne who provided the solution to the longitude problem that was actually used in most maritime vessels well into the nineteenth century.[20] Harrison's chronometers, while accurate, were at £200 far too expensive to be widely deployed; Maskelyne's Nautical Almanac, on the other hand, cost two shillings six pence, and when combined with a £8 Hadley's quadrant and an equally inexpensive book of mathematical tables, provided the cheap and effective means of determining longitude that would continue to dominate navigation for the next half-century.

At the heart of Maskelyne's longitude solution was his development of effective computational techniques. Although these techniques were

17. Sara B. Pritchard, "Toward an Environmental History of Technology"; Dolly Jørgensen, Finn Arne Jørgensen, and Sara B. Pritchard, eds., *New Natures*.

18. Fabian Prieto-Nanez, "Postcolonial Histories of Computing"; Nathan Ensmenger, "Computation, Materiality, and the Global Environment."

19. Dava Sobel, *Longitude*.

20. Mary Croarken, "Tabulating the Heavens."

preindustrial and as such did not require much in terms of mechanization, they bear all the hallmarks of what would soon develop into the computational approach to data processing and management. His distributed network of human computers, whose work was carefully coordinated, monitored, and compiled, anticipated the "information factory" approach to computation that would dominate the nineteenth century and beyond.[21]

In fact, we could tell a compelling history of modern computing simply by following the problem of knowing exactly where in the world you were, and how to get where you wanted to go. For example, consider Charles Babbage, often identified as the great-grandfather of modern computing. Like Maskelyne, Babbage was also an astronomer; like Maskelyne, Babbage was charged by the British government with producing an accurate version of the Nautical Almanac to be used in the pursuit of Imperial ambitions.

The solution that Babbage proposed was also computational, but was constructed around machines rather than people. Babbage's Difference Engine, the basis of his popular status as the great-grandfather of the modern electronic digital computing, was a mechanical implementation of Maskelyne's human-powered method of differences. But the primary contribution of Babbage was not so much as an inventor but as economist: drawing on his extensive observations of contemporary textile manufacturing, Babbage recognized that industrial methods could be applied to informational problems. The idea of the "information factory" would guide developments in information technology for at least the next century, from typewriter to the ENIAC.[22] As historians of computing sensitive to questions of labor and gender have suggested, it is the industrial character of these nineteenth-century information technologies that most critically shapes the technology and structure of commercial computing as it emerges in the middle of the twentieth.[23]

In the early twentieth century yet another British astronomer, Leslie John Comrie, would bring to the Nautical Almanac Office (NAO) the technology of punch-card tabulation, first developed by the American Herman Hollerith. Comrie, who would later found the world's first private computing services company, is often referred to as the father of modern scientific computing. His advocacy for mechanical computation at the NAO led directly to the foundation of the Admiralty Computing Service in 1942 and later to the creation of the National Physical Laboratory's Mathematics Division.[24]

In fact, there is a strong argument to be made that many of the most important moments in the history of computing have involved changes in

21. Martin Campbell-Kelly et al., *Computer*.

22. James Cortada, *Before the Computer*.

23. Thomas Misa, *Gender Codes*; Nathan Ensmenger, "'Beards, Sandals, and Other Signs of Rugged Individualism'"; Marie Hicks, *Programmed Inequality*.

24. Mary Croarken, "Case 5,656."

the ways in which human beings perceive and relate to their environment—one of the traditional themes of environmental history.[25]

Consider, for example, the Hollerith tabulating technology that John Leslie Comrie used to "computerize" scientific data processing. The punch-card technology that Herman Hollerith invented (and IBM later perfected) was itself invented in direct response to another challenge associated with "knowing" the world and the place of humankind within it.

In this case, the massive geographical and demographic expansion of the United States in the mid-nineteenth century had stretched the ability of the U.S. Census Bureau to perceive and measure the nation-state. Not only was it responsible for enumerating and documenting a rapidly growing population, but the government was asking of its more and more detailed questions about the characteristics of that population—and about the natural world on which that population was dependent. Among the 21,000 pages of the Hollerith machine-produced 1880 census were hundreds of maps describing the physical, social, and economic geography of the increasingly united United States. The digital data encoded on a Hollerith punch card would become an essential tool for making the world legible to governments and corporations. The mother/inventor of the Hollerith tabulating machine was the necessity of a decennial census mandated by the U.S. Constitution and greatly complicated by the data requirements of the modern bureaucratic nation-state. Several decades later, a similar dilemma would face the IBM Corporation, the direct successor of the Hollerith firm, when it took on the job of administering the newly established Social Security program.[26]

From the Census Bureau to the National Security Agency, the American government has increasingly perceived its citizens through the lens of an electronic digital computer. These efforts are not simply an extension of the modernist imperative outlined most famously by James Scott in *Seeing like a State*.[27] Computational technologies represented a new way of viewing and organizing the world, and one which has only been lightly touched upon by historians of computing.[28]

The need for governments to "see" the world extended to the environment. As William Aspray, Rick Nebeker, Kristine Harper, and James Fleming (among others) have convincingly argued, the need of the United States government to perceive and predict the weather, largely for the purposes of making war, was an important motivation for its early investments in large-scale computational technologies.[29] And as Sharon Kings-

25. Carolyn Merchant, *The Death of Nature*; Tim Ingold, *The Perception of the Environment*.

26. Lars Heide, *Punched-Card Systems*.

27. James C. Scott, *Seeing Like a State*.

28. A notable exception is Jon Agar's brilliant and quirky *The Government Machine*, which argues that Alan Turing's inspiration for the Universal Turing Machine was the administrative bureaucracy/technology of the British Civil Service.

29. William Aspray, *John von Neumann*; Frederik Nebeker, *Calculating the Weather*; James Rodger Fleming, *Fixing the Sky*.

land (and others) have shown us, the modern science of ecology is a product of computational and cybernetic technologies, as are most of the tools used for environmental impact assessment, natural resource management, and petrochemical exploration and extraction.[30] Finally, as Paul Edwards has recently demonstrated so convincingly, climate science is perhaps the ultimate computational science.[31] Not only are do these climate simulations represent the single largest consumer of computer power on the planet, they challenge in fundamental ways the traditional epidemiological foundations of modern science. In fact, we could argue that the use of computer technology to "know" our environment lies at the cutting edge of the history of computing, from both a technological, social, and epistemological point of view. From the 3D computer models that make possible new extractive processes like hydraulic fracturing, to the use of economic models such as the FORPLAN system (which is used by the national Forestry Service to allocate natural resources), the techniques, assumptions, and politics of computer experts are built into *and then concealed within* the algorithms that shape our world.[32]

Information as Infrastructure

Another way of thinking about the role of geography in the environmental history of computing is to think about information technology as a form of infrastructure. Infrastructures are an extreme example what the historian of technology Thomas Parke Hughes famously described as Large Technological Systems. Unlike individual inventions, Large Technological Systems cannot exist in isolation, but are inextricably linked to other technological, social, political, and economic actors, networks, and processes. The first high resistance filament incandescent light bulb was an invention, in the Hughesian taxonomy; the vast and interconnected network of electrical generation and distribution that are required to light up an entire city is a Large Technological System.

The largest of the Large Technological Systems we often call infrastructure: the electrical grid, the sewer system, the interstate highways, the AT&T network. Infrastructures are critical enabling technologies; their primary purpose is to make other technological and commercial activities possible. As a result, as Susan Leigh Star and Karen Ruhleder have reminded us, infrastructures are intended not to be seen.[33] Technologies become infrastructure only after they are perfected to the point of being routine. We notice them only when they fail.

30. Sharon E. Kingsland, *The Evolution of American Ecology*.

31. Edwards, *A Vast Machine*.

32. Leslie Liberi and J. E. de Steiguer, "The Role of Computerized Models"; Jennifer Gabrys, *Program Earth*.

33. Susan Leigh Star and Karen Ruhleder, "Steps Toward an Ecology of Infrastructure."

The global Internet is in that respect the perfect infrastructure: it is omnipresent and invisible; everywhere and nowhere. Using it we can connect to anyone, anywhere, from anywhere, but it does not otherwise intrude on our material reality. In our post-industrial society, information technologies make place and space increasingly irrelevant. Distance is dead, the world is flat; the singularity is near.[34] Except, of course, when they are not.

In recent years scholars such as Geoffrey Bowker, Paul Edwards, and Steve Jackson have demonstrated the power of applying infrastructure studies to the study of scientific practice.[35] By digging even more deeply into the multiple layers of infrastructure that make possible the information economy—by engaging in what Susan Leigh Star and Geoffrey Bowker have called infrastructural inversion—we can turn on their head some of the conventional assumptions about the true nature and costs of these infrastructures.[36]

Consider, for example, the digital currency Bitcoin, about which much as been written recently. There are many fascinating political, economic, and technological issues raised by the existence of a thriving international Bitcoin market, including important questions about legal jurisdiction, government regulation, and the ontology of money.[37] For the purposes of this paper, however, what matters most about Bitcoin is that it reveals the inextricable relationship between digital products and the real-world material inputs required to make those products a "reality." A Bitcoin itself is an entirely virtual commodity, meaning that it exists only as a string of binary digits in a distributed digital ledger known as a blockchain. But the information infrastructure that creates and operationalizes Bitcoin as a functional currency is shockingly tangible: by current estimates the Bitcoin network represents more computing power—by several orders of magnitude—than that of all of the top 500 supercomputers in the world combined. The daily electricity requirements of this computer power puts the Bitcoin network somewhere between the nation-states of Ireland and Denmark in terms of annual energy consumption.[38]

What is most remarkable about Bitcoin's insatiable demand for electricity is that it is in fact a feature, and not a bug. As Zac Zimmer so ably described in a recent article in this very journal, Bitcoin is an artifact with politics: in order to circumvent the need for a central authority to create and regulate its currency, the process of "mining" a Bitcoin (the metaphor

34. Frances Cairncross, *The Death of Distance*; Thomas L. Friedman, *The World Is Flat*; Ray Kurzweil, *The Singularity Is Near*; John Mark Newman, "The Myth of Free."

35. Steven J. Jackson et al., "Understanding Infrastructure"; Edwards, *A Vast Machine*.

36. Geoffrey C. Bowker and Susan Leigh Star, *Sorting Things Out*.

37. Edward Castronova, *Wildcat Currency*.

38. David Malone and Karl J. O'Dwyer, "Bitcoin Mining and Its Energy Footprint"; Timothy Lee, "Bitcoin's Insane Energy Consumption."

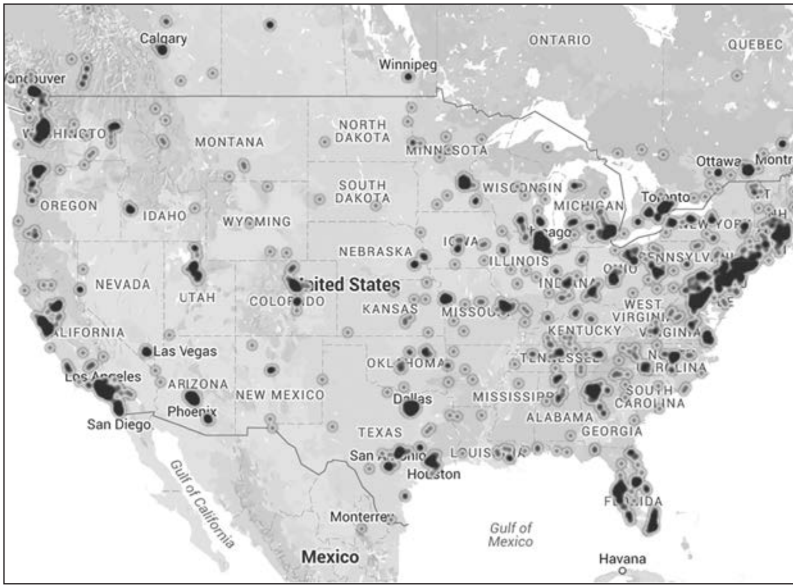

FIG. 1 Bitcoin activity, 20 September 2013. (Source: Image by author based on Google Maps.)

here is revealing) is deliberately wasteful of energy.[39] For every Bitcoin mined, and indeed every Bitcoin transaction processed, the global network of Bitcoin infrastructure engages in a race to solve an arbitrary but computationally expensive puzzle. And to make matters worse, the difficulty of that puzzle is being constantly adjusted. It is an infinite sink for computing power—and by extension, the coal, oil, gas, water, and/or uranium required to generate the electricity that produces that computer power.

To bring our attention back to history and the environment: if space and place were indeed irrelevant in Cyberspace we might expect to see Bitcoin mining activity even distributed when mapped against physical geography. In fact, as Figure 1 illustrates, Bitcoin mining tends to cluster in specific regions. And since the key input to the Bitcoin mining process is electrons, we should not be surprised to see the virtual map of Bitcoin activity corresponds closely to physical infrastructure of the electrical power grid, as illustrated by Figure 2. Note as well the proximity of nuclear power plants; again, this is anything but a coincidence.

In fact, the power grid is not the only traditional physical infrastructure that corresponds to this virtual commodity. The power grid, a largely twentieth-century innovation, is itself constructed around the nineteenth-century railroad network. The reasons for this will be familiar to both historians of technology and environmental historians via William Cronon's classic *Nature's Metropolis* which, among other things, tells the story of how

39. Zac Zimmer, "Bitcoin and Potosí Silver."

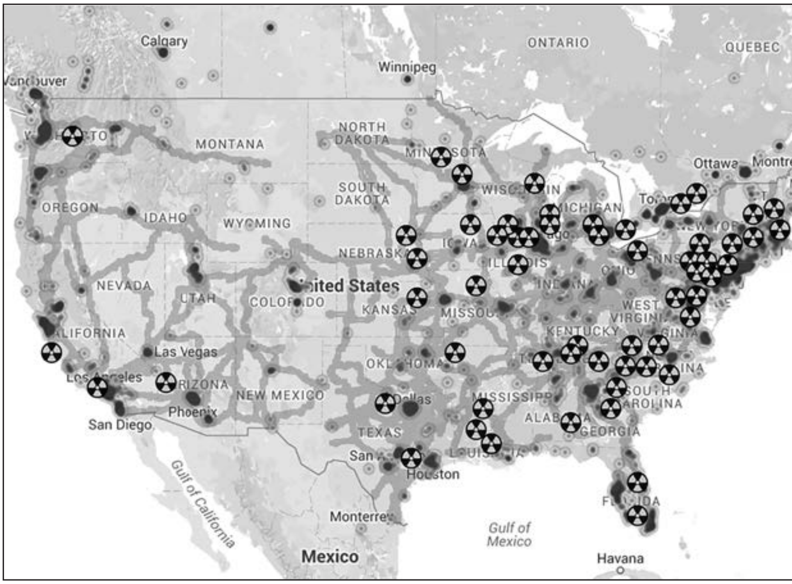

FIG. 2 Bitcoin activity mapped against nuclear power plants, electrical power distribution grid. (Source: Image by author based on Google Maps.)

the American railroad network helped knit together—physically, economically, and symbolically—the United States in the mid-nineteenth century.[40] The rise of the railroad both enabled, and was enabled by, the simultaneous development of the telegraph network; in many ways they were co-constructions.[41] The railroad needed the telegraph for the purposes of communication and control. A series of nasty railroad accidents in the early nineteenth century highlighted the need for careful coordination of traffic, and by the end of the 1850s most railroads had adopted the telegraph as a mechanism for signaling and traffic control. At the same time, the railroad served as the perfect foundation for the growth of the telegraph system. Railroads were flat, cleared pathways along which it was easy to construct and maintain the long strings of copper wire required by the telegraph network.

Collectively these infrastructures enabled the nineteenth-century annihilation of space and time that made possible the exploration—and exploitation—of vast amounts of previously unclaimed or inaccessible resources. For a graphical illustration of this, recall a moment your dog-eared copy of Merritt Roe Smith and Leo Marx's *Does Technology Drive History*: on the cover was a reproduction of John Gast's 1872 painting *American Progress*, which featured Lady Liberty leading her people West, trailing in her wake both a railroad line and a telegraph wire.[42] Both technologies were

40. William Cronon, *Nature's Metropolis*.
41. Richard R. John, "Recasting the Information Infrastructure."
42. Merritt Roe Smith and Leo Marx, *Does Technology Drive History*.

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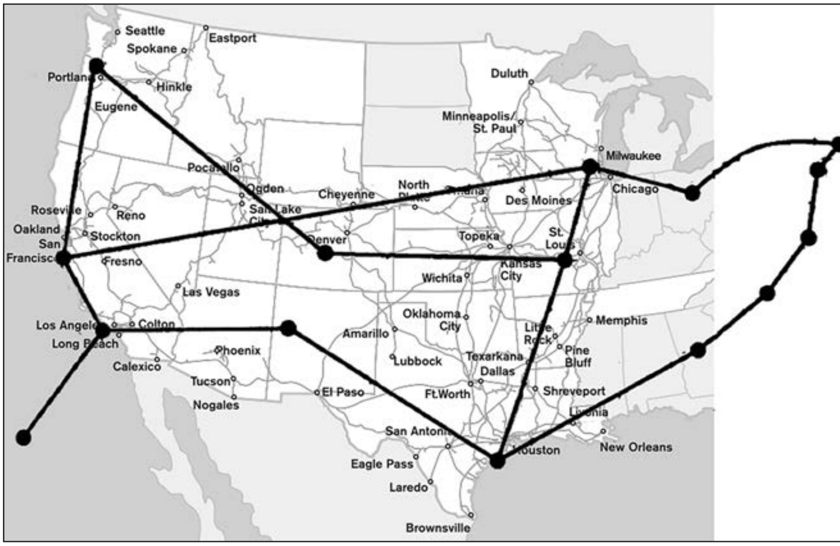

FIG. 3 NSFNet (1991) superimposed over the Southern Pacific Railroad network. (Source: Image by author based on Google Maps.)

considered to be essential to the accomplishment of America's Manifest Destiny. In fact, from the from the American West to Cecil Rhodes's South Africa, the link between information and empire was readily apparent to contemporaries.[43]

Now consider this map (figure 3), which overlays the Southern Pacific Railroad network from its heyday in the late nineteenth century with the NSFnet network (a successor the ARPAnet and a close precursor of the modern Internet) of the early 1990s. Although one is a physical map and the other is symbolic, you can see how closely the infrastructure of the computer network aligns with the traditional geography of the railroad network. This is not a coincidence. As with the telegraph network, the Internet was built around (and in some cases by) the railroad company. In fact, a unit of the Southern Pacific Railroad company charged with maintaining microwave communications towers and fiber optic cables along its right-of-way eventually spun off as the Southern Pacific Railroad Internal Network Telecommunications company, or SPRINT.[44] Today SPRINT is the third largest telecommunications carrier in the United States, and is a Tier-1 Internet Service provider, operating major segments of the national Internet backbone infrastructure.

And so once again, when we look closely at the flows of material that make the virtual possible, we discover that many of most significant social and economic nodes of the Information Society sit at the intersection of

43. Daniel R. Headrick, *The Tentacles of Progress.*
44. Tom Zoellner, *Train.*

traditional, material infrastructures like railroads, power grids, and river systems. The Information infrastructure of the twenty-first century is built around the bones of the nineteenth-century transportation and communication networks. These were in turn constructed along riverbeds and mountain passes. Geography shapes technology, and vice versa.

Of course, Bitcoin is not the only virtual activity that requires a close connection to the physical environment. In fact, most Bitcoin "mines" are co-located with other centralized computational activities. We call these centers of activity data warehouses, data farms, server farms, or more recently, the Cloud.

The Cloud is a Factory

The Cloud is a brilliant and wickedly misleading metaphor. It implies both ubiquity and ethereality. What tech services companies want us to know about the Cloud is that it is always available, largely transparent to its users, and never needs much thinking about. In other words, the Cloud is the perfect infrastructure. But unlike traditional infrastructure like roads and bridges and sewer systems, the Cloud seems to require no violence to the physical environment. It floats above, silent and unobtrusive, a force of nature rather than a human-built technology.[45]

Recently, Google has made available a series of images of its Cloud facilities.[46] For the most part, they are beautiful and quieting images, a post-industrial reinterpretation the visual genre that David Nye has referred to as the "technological sublime"—although viewers familiar with Paul Edward's work on the Closed World might also find these sterile and uninhabited landscapes a little unsettling.[47]

But as the media historian and social theorist John Durham Peters has suggested, although the rhetoric of the Cloud has mobilized by the Internet giants to invoke images of ethereal otherworldliness, Google is a fire-god, and not a spirit of the air.[48] In 2011, for example, Google data centers used more than 2.3 billion kilowatt-hours of electricity, which represented about 2 percent of the annual electricity consumption of the entire United States. That same year, Facebook consumed an additional 532 million kilowatt hours. The collective global demand for power for digital data centers accounts for the output of roughly thirty nuclear power plants.[49] As more of the developing world acquires access to the Internet, it is expected that the total energy requirements for the cloud will grow by 60 percent by 2020.[50]

45. Tung-Hui Hu, *A Prehistory of the Cloud.*
46. Steven Levy, "Google Throws Open Doors to Its Top-Secret Data Center."
47. Paul N. Edwards, *The Closed World.*
48. John Durham Peters, *The Marvelous Clouds.*
49. James Glanz, "Power, Pollution and the Internet."
50. Skip Laitner and Mike Berners-Lee, *SMARTer 2020.*

And as mentioned earlier, if the Cloud were a country, it would be the sixth largest electricity consumer in the world.

Of course, where energy is used, heat is created. Cooling even a medium-sized high-density server farm can require as much as 360,000 gallons of clean, chilled water a day. The new NSA Intelligence Community Comprehensive National Cybersecurity Initiative Data Center in Bluffdale, Utah will consume 1.7 million gallons every day.[51] Such consumption patterns stretch the limits of almost any municipal water supply, and given the looming global shortage of clean water, water scarcities represent one of the many unanticipated consequences of computing whose implications are only just beginning to be realized.

Across the United States and presumably the world, the invisible infrastructure of the Internet follows the contours of geography and human settlement. When big data providers like Google and Microsoft locate their server farms, they have to take into consideration the same factors that guided more traditional manufacturers in the Industrial Era: transportation networks, water supplies, power grids, labor markets, and a local political climate amenable to development. When Microsoft chose to locate a new data warehouse in the small farm town of Quincy, Washington, for example, it was pursing not only the availability of cheap hydroelectric power, but also lucrative tax breaks. Like any factory moving into a community, they promised local residents jobs, tax revenue, and the ability to maintain their rural lifestyle in the face of a decades long decline in the local agricultural economy.[52] In an earlier era, Fairchild took the first steps towards the globalization of the microelectronics industry with an experiment at the Navajo reservation in Shiprock, New Mexico; as Lisa Nakamura reminds us, this choice of location was not an accident, but rather the product of a long social, political, and environmental history of that particular place and people.[53]

I have elsewhere argued that that computerization of modern society can only be understood in the context of a much longer process of the industrialization of information processing.[54] Like the term "Cloud," the term "post-industrial" can conceal more than it illuminates. By treating the Cloud as a type of factory and not an idealized abstraction, we can re-situate the history of computing in the larger history of the American industrial development and ask new and important questions about labor, capital, politics, and power (in a variety of meanings of that word). If the Cloud is a factory, what kind of a factory is it? Who works there, and what kind of work to they do, and how is it different from the type of work previously performed by factory workers? Where does it fit in a larger technological,

51. Hogan, "Data Flows and Water Woes."
52. Glanz, "Power, Pollution and the Internet."
53. Lisa Nakamura, "Indigenous Circuits."
54. Nathan Ensmenger, *The Computer Boys Take Over*.

labor, and environmental history of human industry? And perhaps most importantly, how did it come to be seen as categorically different?[55]

Being Digital, Revisited

When Nicholas Negroponte declared in his 1995 *Being Digital* that information was immaterial, he was fundamentally mistaken. But the title of his book, and the more general historical question of what it means for a society or entity to think of itself as "being digital," is an important one. In terms of the environmental historical contribution to this question, I am inspired by the work of the historian of science and technology Gabrielle Hecht. In her recent book *Being Nuclear*, Hecht details the many ways in which the struggle for control over uranium, the core component of both atomic weapons and nuclear power plants, has shaped African political, social, and economic life, as well as the lives and health of thousands, if not millions, of African workers and citizens.[56] She shows how the relationships between the "nuclear powers" (often former colonial powers) and the "developing nations" (often former colonies) were constructed around previously established networks of political influence, commercial exchange, and the movements of goods and people. Her work demonstrates the necessity (and value) of adopting a global perspective, even when dealing with technologies that are predominantly associated with Western industrial nations; in her analysis, impoverished African miners are as much participants in the history of the nuclear economy as are scientists, engineers, and politicians.

Historians of computing have much to learn from *Being Nuclear*. Among other things, control over the supply of key minerals is as important to the computer industry as it is to the nuclear nation-state. Participation in the digital economy is therefore not confined simply to those who produce or operate digital devices. Seen from this perspective, the digital economy is a global phenomenon, even though access to digital technologies is not.

For example, consider the case of lithium carbonate, a central component of the batteries used in everything from the Apple iPad to the Tesla Model S.[57] Almost half of the world's supply of lithium carbonate is found in Uyuni region of Bolivia, not far from the city of Potosi. In the early sixteenth century, Bolivian silver provided much of the wealth of the Spanish Empire. The city of Potosi, founded in 1545, was for a time the largest city in the New World, with a population that exceeded 150,000. Needless to say, Bolivians in this area have a long history of interaction with foreign

55. Allison Carruth, "The Digital Cloud"; Louise Amoore, "Cloud Geographies"; Mél Hogan, "(Another) Battle in the Clouds."

56. Gabrielle Hecht, *Being Nuclear*.

57. Seth Fletcher, *Bottled Lightning*.

nations in search of valuable minerals, as do their neighbors in Chile and Argentina, also large suppliers of lithium carbonate.[58] In the digital era, the politics of mineral extraction, foreign investment, and neocolonialism have once again emerged as central concerns of South and Central American government.[59] As Saul Villegas, the head of the government-run organization that oversees lithium extraction in Bolivia, recently declared: "The previous imperialist model of exploitation of our natural resources will never be repeated in Bolivia." You can imagine what this kind of rhetoric sounds like to the heads of major American high-tech firms.[60] The electric car company Tesla, for example, is on track to becoming the largest consumer of lithium-ion batteries in the world. The have recently negotiated with Nevada to locate a "gigafactory" in that state; in exchange, Nevada has committed to developing the Chemetall-Foote lithium mine. Nevada taxpayers will be asked to construct a connector between the Tesla Gigafactory and Highway 50 ("the loneliest road in America"), whose sole purpose is to connect the Chemetall-Foote mine with the proposed Tesla Gigafactory.

Lithium is not the only mineral component of modern electronics for which there is great and growing demand. Tesla batteries also require cobalt, which is a conflict mineral (the major supplies are located in the Democratic Republic of Congo, notorious for its use of child and slave labor in the gold mines from which cobalt is also extracted).[61] Another example is tin. Nearly half of global tin supplies are used to make solder for electronics. About 30 percent of the world's tin comes from the islands of Bangka and Belitung in Indonesia, where an orgy of unregulated mining is reducing a rich and complex system of rainforests and gardens to a post-holocaust landscape of sand and acid subsoil. Tin dredgers in the coastal waters are also wiping out the coral, the giant clams, the local fisheries, the endangered Napoleon wrasse, the mangrove forests and the beaches used by breeding turtles. In addition, the process of tin mining is low-tech, labor-intensive, and extraordinarily dangerous to the workers who often sit for hours in a slurry of toxic mud. Among other ailments, exposure to tin can cause skin and tissue irritation, and ingestion nausea, vomiting, diarrhea, abdominal pain, fatigue, and tremors. Long-term exposure can damage the liver and kidneys, and can have long-term neurological effects.[62]

Finally, there is the case of the seventeen rare earth elements, five of which are particularly valuable to the electronics industry. These include yttrium, which is used in LCD screens and fuel cells; europium, a key component of compact fluorescent lights, computer monitors, and iPhone

58. Juan Carlos Zuleta, "Bolivia."
59. Ibid.
60. Jean Friedman-Rudovsky, "For Lithium Batteries."
61. Debapratim Purkayastha and Syed Abdul Samad, *Apple and Conflict Minerals*.
62. Mats Ingulstad, Andrew Perchard, and Espen Storli, *Tin and Global Capitalism*.

screens; and neodymium, terbium, and dysprosium, all essential ingredients in the magnets of wind turbines and computer hard drives.

Global demand for rare earth elements has more than doubled in the last decade, largely as a result of the high-tech industry. With continued global growth of the middle class, especially in China, India, and Africa, demand will continue to grow.[63] But aside from the a small amount recovered during recycling, the United States is 100 percent reliant on external sources of rare earth elements. At the moment, China currently supplies 97 percent of global rare earth metal demand and 100 percent of certain specific rare earth metals, such as terbium and dysprosium.[64] Already, the Chinese government has used its monopoly over certain rare elements to "encourage" Western high-tech companies to locate their factories in China, and many analysts are predicting that the struggle for control over rare earth resources will only grow more contentious. As Deng Xiaopeng famously declared in 1997, "The Middle East has oil, we have rare earth."

It would be possible to follow the chain of materials required to construct digital devices around the world and across the periodic table. According to a recent United Nations study, the production of just one desktop computer required 240 kilograms of fossil fuels, 22 kilograms of chemicals, and 1,500 kilograms of water.[65] Each one of these resources and resource-chains represents a set of stories to be told about global politics, international trade, worker safety, and environmental consequences.

To bring the story back around to its the beginning, the series of transnational movement and exchanges of materials that make possible digital technology are also the products of that technology. I have already discussed the centrality of the problem of navigation in the history of computing. One of the most revolutionary developments in the more recent history of global capitalism was the invention, in the late 1950s, of the standardized metal shipping container.[66] By dramatically reducing the time required to unload cargo—instead of moving materials from one container to another, the entire container would be lifted from the ship and placed directly on a train or truck—containerized shipping increased throughput and reduced cost simultaneously. In the half-century following the introduction of the containerized shipping, global trade has increased twenty-seven times over. By the year 2000, 300 million 20-foot containers were moved by sea each year. And in addition to increased scale, the geography of trade has changed with containerization; port cities whose environmental history made them centers of human settlement and exchange for thousands of years have recently found themselves sidestepped in favor previously marginal harbors capable of accommodating the massive, increasing

63. Veronese, *Rare*; Hanna Vikström, "Spectre of Scarcity."
64. Jeff Nesbit, "China's Continuing Monopoly over Rare Earth Minerals."
65. Ruediger Kuehr and Eric Williams, eds., "Computers and the Environment."
66. Alexander Klose, *Container Principle*.

unmanned container ships and the automated terminals that connect them to other infrastructures.

The story of containerized shipping is, of course, in large part the story of the container. But it is equally a story of computerization. Computers were used to track, organize, and direct the millions of identical containers—as well as to control the automated cranes that were used to unload them. Today, computer controlled and GPS guided drone ships are poised to further revolutionize the industry.[67] We often think that digital technologies *eliminate* the need for the physical movement of materials and people. The case of containerized shipping suggests one of the many ways in which information technologies *facilitate the expansion* of such movement.

Digital Residues

Every year, the world disposes of almost 50 million tons of electronic waste. Much of this e-waste contains a least some measure of environmentally hazardous materials, including beryllium, cadmium, mercury, and lead. The vast majority of this waste ends up in landfills in parts of the world (primarily India, China, and Africa) where environmental and worker-safety regulations are relatively lax. In a recent expose of a "computer graveyard" in Agbogbloshie, Ghana, journalists with the BBC discovered that thousands of tons of illegal e-waste was being transported into the area each year.[68] Of this illegal waste, only 10 percent was recycled; the other 90 percent, which included lead, dioxin, and other toxins and carcinogens, was dumped directly into primitive landfills, where it quickly contaminated the water supply. Even the materials that were recycled were harmful to the environment: over open fires fueled with equally hazardous materials, workers as young as nine years old melted down components to extract valuables such as copper, aluminum, and mercury. Both the smoke from the fire and the materials they reclaimed represent personal and environmental dangers.[69] In a 2008 study, researchers at Greenpeace discovered high levels of lead, cadmium, antimony, PCBs (poly-chlorinated biphenyls), and chlorinated dioxins in the soils in Agbogbloshie.[70]

This is, of course, the end of the story, the final destination of my imagined global lifecycle of digital technologies. As we have seen throughout this history, information technology does not so much eliminate as conceal the materiality of the so-called "new" economy. It externalizes the costs and centralizes the benefits. This is particularly true in the case of the envi-

67. Joshua Ganz, "Inside the Black Box."

68. Raphael Rowe, "Britain's E-Waste Illegally Leaking."

69. Alexis Madrigal, "The Hardware Scavengers of Ghana"; Pieter Hugo, "A Global Graveyard."

70. Jo Kuper and Martin Hojsik, *Poisoning the Poor*.

ronmental pollution associated with both the production and disposal of electronic goods.[71]

It is important to note that the problem of digital pollution is not only a problem of the developing world. Many Americans are unaware, for example, that the single largest concentration of Superfund sites (that is to say, locations designated by the EPA as particularly polluted and in need of immediate remediation) is located in Silicon Valley. In the roughly 10 by 40-mile strip of land that comprises Santa Clara County, California, there are twenty-three Superfund sites, most of them contaminated by the by-products of semiconductor manufacturing, including such highly toxic chemicals as trichloroethylene, Freon, and PCBs.[72] These chemicals have been linked to elevated rates of miscarriages, birth defects, and cancer. So far more than $200 million has been spent on cleaning up soil and groundwater pollution in the area, and the extent of the problem is only just starting to be addressed. Similarly, Endicott, New York, the home of the IBM Corporation's most famous company towns, is the victim of a 300-acre toxic plume of trichloroethylene, a cancer-causing solvent.[73] It is safe to say that most of the well-educated and well-paid engineers and scientists who live in these areas are unaware of the environmental dangers posed by their seemingly clean "smokestack-free" post-industrial information industry.

Conclusion

Silicon Valley is an appropriate place to wrap up this survey of the environmental history of computing, because in part this is where the larger project began. This is not simply the obvious association of Silicon Valley with the history of computing, but rather because Silicon Valley is arguably the most striking example of the paradox of place that sits at the center of the digital economy. Silicon Valley makes the technologies that are supposed to make place irrelevant, and yet its own significance as a place remains remarkably persistent. Despite the fact that it contains some of the most expensive real estate in the world—and is both overcrowded and polluted—high-tech and Internet firms still flock to Silicon Valley; and despite many attempts to replicate its magic in industrial and university cities around the globe, no one has ever succeeded. As AnnaLee Saxenian and others have amply demonstrated, geography still matters, even in the heart of the high-tech information industry.[74]

71. Elizabeth Grossman, *High Tech Trash*; Jennifer Gabrys, *Digital Rubbish*.

72. Christopher Helman, "Google Buildings Polluted"; Benjamin Pimentel, "The Valley's Toxic History"; Lenny Siegel and John Markoff, *The High Cost of High Tech*; Christophe Lécuyer, "From Clean Rooms to Dirty Water."

73. Peter C. Little, *Toxic Town*.

74. AnnaLee Saxenian, *Regional Advantage*.

But Silicon Valley illustrates the ways in which both history and environment matter as well. We also can peel back the layers of the Santa Clara county landscape to reveal multiple sediment strata of industrial activity and infrastructure. In the conventional histories of computing, the prehistory of Silicon Valley is that of an idealized agrarian economy—Santa Clara county contains some of the most fertile soil in the United States, and indeed was formerly known as the "The Valley of Dreams," "The Valley of the Heart's Delight," "The Fruit Bowl of America," and the "Garden of the World." But the extensive but undocumented underground water system that carried the pollution of the semiconductor industry was laid down during the era of industrial agriculture, and the canneries of Santa Clara county were once the heaviest polluters of the San Francisco Bay.[75] And prior to that, quicksilver mines in New Almaden and other towns radically transformed the landscape using destructive hydraulic mining techniques. Both industries relied heavily on immigrant labor migrating back and forth between California and Mexico—this same migrant labor force was essential to the growth of the early semiconductor industry. There is a racial and ethnic geography from this period that still persists in Silicon Valley—and over which maps similarly segregated rates of environmental pollution and human health effects.[76]

And yet Silicon Valley has also worked hard—and largely successfully—to erase both its own past and its connections to the material world.[77] By distancing itself from the past, the computer industry can claim the positive benefits of technological progress without bearing any of the burdens of the larger technological history of which it is only the most recent iteration. Automobiles pollute, nuclear energy produces toxic waste, industrial agriculture is giving us all cancer—but computers keep getting faster, smaller, better. By making the physical world increasingly irrelevant, information technologies allow us to avoid confronting the consequences of our actions on the environment. We assume that by putting things online we are removing them from realm of the physical, and that going digital means going green. In some cases this may be true; in others it is clearly not.

And so, in addition to contributing to the literature in the history of computing and environmental history, I hope that this project will also lead to the development of a new environmental ethic of design in information technology. Bitcoin is an ill-conceived, entirely unnecessary, environmental disaster, but the "proof of work" requirement that makes it so is not an essential requirement of a digital currency. Once we accept that the provision of "computer power," like other forms of industrial activity, is necessarily resource-intensive, pollution-producing, and potentially

75. Lécuyer, "From Clean Rooms to Dirty Water."
76. David N. Pellow and Lisa Sun-Hee Park, *The Silicon Valley of Dreams.*
77. Peter Schwarz and Peter Leyden, "The Long Boom."

damaging to the environment, we can make more informed choices about when, how, and for what purposes we employ such power.[78] There is no such thing as a free lunch, even in the virtual domain of cyberspace, but there are meals that are less expensive and more sustainable than others.

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78. Nicole Starosielski and Janet Walker, *Sustainable Media*; Matthew N. Eisler, "Exploding the Black Box."

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