Computation, Materiality, and the Global Environment

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This past fall I taught a course on information and computer ethics for undergraduates in our informatics and computing program. Most of the topics that I covered in class were already at least vaguely familiar to my students: privacy, intellectual property, cyber-crime, professional ethics, and the ethics of design.

There was one set of topics, however, that proved almost universally novel and disturbing, even to this reasonably well-informed (and generally jaded) audience. In a series of lectures, I explored the environmental consequences of electronic digital computing. As we traced the global life cycle of a typical laptop computer or cell phone from its material origins in rare earth element mines in Africa and South America, to its manufacture and assembly in the factory cities of China, through its transportation and distribution to retail stores and households across America, and finally to its eventual disposal in places like the slums of Agbogbloshie, Ghana, the students discovered that the computer industry is built on more than just abstractions, algorithms, and information.

Whether it was studying the toxic by-products of semiconductor manufacture, the enormous amounts of energy and water consumed daily by massive Google and Facebook server farms, or the use of child labor in the ''computer graveyards'' of the developing world, my students were forced to confront the fact that computer power comes at a cost and that the physical infrastructure that enables their virtual interactions are resource-intensive, pollution-producing, and potentially damaging to the environment. For many of these aspiring computer professionals, this was a sobering reality.

Global Infrastructure

The point of this series on the global life cycle of computer technology was not to be negative or alarmist, but to make an important point about the material underpinnings of the modern information society. Most of my students had never thought about information technology in terms of the physical infrastructure. To the degree that they thought about materiality at all it was in terms of end-user devices, such as their desktop or laptop computers, smartphones, or tablets. Other than the costs of acquiring these devices, and perhaps those demanded by their Internet provider, access to the vast global network that comprises cyberspace was essentially ''free,'' not only in terms of money but also in terms of other, less immediate costs, such as energy use, human labor, and environmental pollution. Unlike other essential technological systems, such as transportation networks, which have costs, impacts, and material presence that are everywhere apparent—consider, for example, the omnipresence and pervasive influence of the automobile on American social, cultural, economic, and political life—information infrastructure is largely invisible and, seemingly, intangible.

There has been some popular attention paid to the material life of information technology. For example, Andrew Blum's playful and intriguing book *Tubes: A Journey to the Center of the Internet* (HarperCollins, 2012) attempted to untangle for its readers the physical strands (cables, wires, and wireless signals) that comprise the Web. And a recent *New York Times* series explored the rapidly growing demand for power, water, and land created by large data centers.[1] There is also an emerging scholarly community, lead by Paul Edwards and Geoffrey Bowker, among others, interested in the study of what they call ''cyberinfrastructure.''[2] For the most part, however, historians of computing are just beginning to focus on the materiality of computing. There are many benefits to be gained from doing so.

''Clean'' Technology

To begin with, focusing on the electronic digital computer as constructed technology, rather than logical abstraction, helps to ground the conversation about computing and its consequences in tangible objects, specific social contexts, and particular times and places. Although computer scientists are perhaps justified in treating the computer solely in terms of the Platonic ideal of the Universal Turing Machine, almost everyone else has to deal with their less-than-perfect embodiments as specific devices designed by actual people to accomplish particular purposes. Treating the computer as physical artifact, rather than as an ideal, metaphor, or aspiration, can help us avoid the kinds of one-sided utopianism that dominates so much of the conversation about computers and society.

Too often these conversation focus on the perceived benefits of computing while ignoring any of its costs. Highlighting the materiality of information technology, with its attendant environmental consequences,

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1058-6180/13/$31.00

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forces us to address the social, political, and moral dimensions of the information economy. A recent United Nations study estimated that the production of just one desktop computer required 240 kilograms of fossil fuels, 22 kilograms of chemicals, and 1,500 kilograms of water—and that does not include the human labor involved.[3] 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.

Some of these consequences can hit quite close to home. Many Americans are unaware, for example, that Silicon Valley contains the single largest concentration of Superfund sites—that is, locations designated by the US Environmental Protection Agency as being particularly polluted and in need of immediate remediation. In the roughly 1,300 square miles of Santa Clara County, California, there are 29 Superfund sites, most of them contaminated by the by-products of semiconductor manufacturing, including such highly toxic chemicals as trichloroethylene, Freon, trichloroethane, and polychlorinated biphenyls (PCBs). 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. Most of the well-educated and well-paid engineers and scientists who live in the area are unaware of the environmental dangers posed by their seemingly ''clean'' postindustrial information industry.

The problem of pollution associated with the production (as opposed to the disposal) of consumer electronics is, of course, even more significant in regions outside of the United States. Most of the manufacturing of these products has shifted to countries like China, whose environmental and worker-safety regulations are notoriously lax. The recent controversy about labor conditions in Apple Computer's Foxconn facility, where as many as 400,000 workers inhabit a 1.16 square mile walled ''campus,'' made many Americans aware that the hazards and pollution associated with computer manufacturer have not disappeared; they have only been shifted abroad. This highlights a second virtue of exploring the life cycle of information technology: This is an essentially international story, one which necessarily shifts the focus from (typically American, or at least Western) users toward a broader range of workers and production sites.

The disposal of ''old'' technologies raises particularly problematic concerns. In a recent expose of a ''computer graveyard'' in Agbogbloshie, Ghana, journalists with the BBC discovered that more than 50 tons of illegal e-waste was being transported into the area each year.[4] 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. In a 2008 study, researchers at Greenpeace discovered high levels of lead, cadmium, antimony, PCBs, and chlorinated dioxins in the soils in Agbogbloshie.[5]

Energy Costs

One of the most interesting developments in the recent literature on computing and the environment is the increased attention being paid to the energy cost associated with informational transactions. The center of gravity of cutting-edge research in computer hardware design has shifted over the past decade from performance to energy consumption. This is in part because engineers are starting to approach the physical limits associated with transistor density; in order to keep up with their relentless pursuit of

Moore's Law, they need to reduce the energy consumed by, and more importantly the heat produced by, their increasingly nanoscale components. In addition, the shift toward mobile technologies has driven demand for smaller, lighter, and more energy-efficient processors, storage devices, and batteries. And perhaps most significantly, the growth of large-scale, data-driven Internet companies and services (such as Google, Netflix, and Amazon) have required an enormous investment in new energy-production and heat-dissipation infrastructure. The collective global demand for power for digital data centers accounts for the output of roughly 30 nuclear power plants, according to a recent article in the *New York Times*, with server farms in the United States accounting for as much as one-third of this total load.[6]

In rural areas across the nation, companies such as Amazon and Microsoft are building enormous data centers—along with their requisite power stations—to power the Internet economy. Generators at Microsoft's Santa Clara, California, facility now represent the largest diesel polluter in the entire Bay Area. In its Quincy, Washington, facility, Microsoft has already been fined more than $200,000 for environmental violations. A large data center can account for as much energy use as a medium-sized town, and that does not include the cost (and hazards) associated with the massive banks of lead batteries that are used as backup insurance against short-term power interruptions.

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 water a day. At an AT&T data center in Ashburn, Virginia, more than 1.35 million gallons of chilled water are required daily. 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, with implications that are only just beginning to be realized.

The Role of Historians

The history of computing has a long and admirable traditional of dealing with both the material and intellectual elements of information technology. But in turning its attention to the larger systems of material production and distribution essential to (and enabled) by computer technology, we can further expand the scope of our discipline, addressing issues of concern to the entire global community.

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References and Notes

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