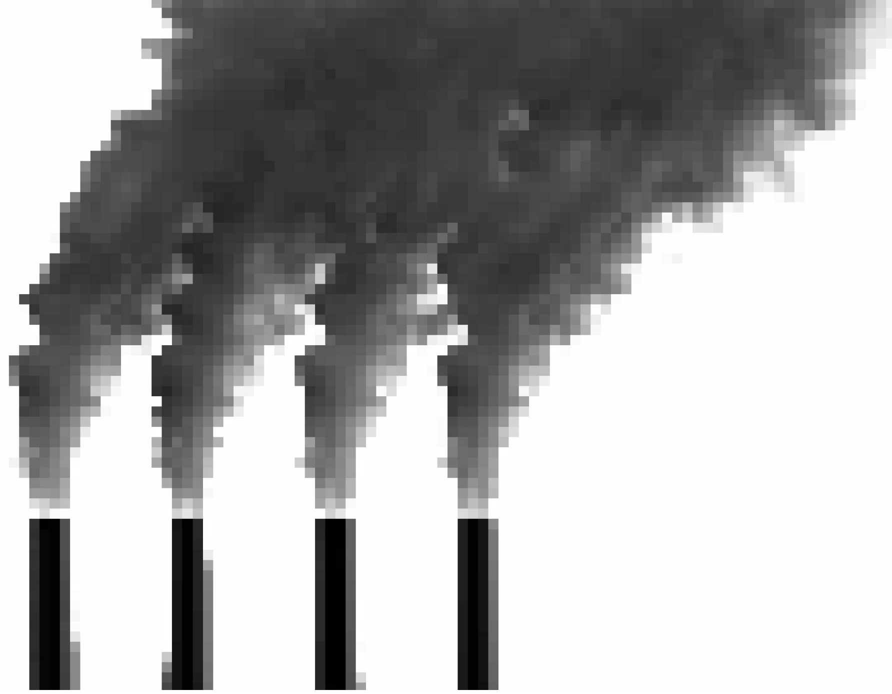

Computing and the Environment

INFO I400/I590 • Fall 2022

One of the more persistent and popular explanations of why the modern "Information Age" is so radically different from other eras in the history of technology has to do with the perceived immateriality of information technology. Whereas other technological revolutions were so clearly associated with the production of physical artifacts and the consumption of material resources, the increasing computerization of society seems to be moving us towards a less resource-intensive and environmentally impactful form of living.

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").

In this course we will explore the intersection between the digital and the material worlds, and will attempt to answer the following questions:

- how has the human desire to understand and manipulate the environment shaped the development of computer and information technologies?
- how do the computer and information technologies that we have developed shape the way we perceive, study, and understand the natural world?
- what are the effects of the digital economy on the global environment, and how can we measure these effects and compare them to earlier or alternative modes of human social and economic activity?
- how can we build sustainable technological infrastructures that better reflect our environmental values, goals, and economic and political agendas?

Although we will deal with technical topics in this course, we will do so in a way that will be accessible to all of you, no matter what your chosen major or level of experience. There are no pre-requisities, other than curiousity and attentiveness.

Professor Nathan Ensmenger <nensmeng@iu.edu>
Myles Brand Hall E226
Office Hours: Tuesday 10-11 am, Friday 12-1 pm

Associate Instructors:
Anne Tally <actally@iu.edu>

I400 Course Details

The class is scheduled to meet on Monday and Wednesday afternoons from 3:10-4:30 in TEF160. This is the classroom located in the Luddy Living & Learning Center in the Teter Quad.

Grading

Your grade for this course will be based on three main components:

- each week you are expected to do the readings and to attend each course meeting.
- each week you will have a short assignment. These will be based on the readings and/or the lecture material, and will generally focus on applying concepts to real-world case studies. Collectively, these assignments will comprise 40% of your overall grade for the course.
- in addition to the weekly assignments, there will be three larger assignments (due at the ends of week 5, week 9, and week 13). Each of these assignments will represent 20% of your total grade.
- finally, throughout the semester there will several occasions for you to earn extra credit points. The exact nature and points awarded will be determined as opportunities arise.

It is my goal to have all of your assignments graded within one week of them being due. It is also my goal to respond to all student emails within 24 hours.

Office Hours

I will be holding regular office hours on Tuesdays from 10-11, and on Fridays from noon-1. I will be holding these simultaneously in-person (Myles Brand Hall E226) and online at https://iu.zoom.us/j/3721147179.

Course Schedule

I A series of tubes? Information as Infrastructure

How do we think about the material dimensions of immaterial information? What exactly is the Internet? How does thinking about the Internet as a form of infrastructure (or not) shape the way we think about its implications for the environment?

Reading(s):

Frans Berkhout and Julia Hertin. 2004. "De-Materialising and Re-Materialising: Digital Technologies and the Environment." *Futures* 36, no. 8 (October): 903–920

Nathan Ensmenger. 2018. "The Environmental History of Computing" [in en]. *Technol. Cult.* 59 (4S): S7–S33

Supplementary Materials

There are some excellent single-topic books exploring the various infrastructures that enable the modern Information Society, from the telegraph to fiber-optics: Hecht (2004), Müller (2016), Starosielski (2015), Jones (2014), Blum (2013), and Carse and Lewis (2017). But infrastructure studies as a more general approach to understanding socio-technical systems has emerged in recent years as compelling body of literature. Star and Ruhleder (1996) is a classic.

The BBC recently did a piece on how Bitcoin consumes more electricity than Argentina. If you are interested in more detailed data, Cambridge University publishes a regularly updated Bitcoin Electricity Consumption Index.

For a rebuttal to the "Bitcoin wastes Energy" argument, see this piece at Coindesk, which is representative. Not that it does not actually deny the figures on energy use, just argues that they are worth consuming.

For some fascinating accounts of the overlap of Bitcoin infrastructure with earlier forms of industrial infrastructure, see A New York Power Plant Is Mining $50K Worth of Bitcoin a Day; The Hard-Luck Texas Town That Bet on Bitcoin—and Lost; The Mountain West Is Experiencing A Second Gold Rush. This Time They're Mining Bitcoin; Will Cryptocurrency Be Alberta's Next Big Boom?; and Iceland's Big Bitcoin Heist

II The Cloud is a Factory

If the Cloud were a country it would be the sixth largest consumer of electricity on the planet. Despite its seeming ethereality, the Cloud is actually a vast web of physical objects, built and operated by human labor, occupying space and consuming resources.

Reading(s):

Nathan Ensmenger. 2021. "The Cloud is a Factory." In *Your Computer is on Fire,* edited by Thomas S Mullaney et al., 29–50. MIT Press

Oró, Eduard, Victor Depoorter, Albert Garcia, and Jaume Salom. 2015. "Energy Efficiency and Renewable Energy Integration in Data Centres. Strategies and Modelling Review." *Renewable and Sustainable Energy Reviews* 42 (February): 429–45.

ARTICLE: How Big Data Saved the Mountain Town

Supplementary Materials

For a global map of data centers, see the Data Center Map Project. For a short but provocative essay on the politics of data geography, see Locating Servers, Locating Politics. For an optimistic assessmentof the climate-changing potential of sustainable data centers, see . For some examples outside of the United States, see Google's solar powered data centre? A good solution, but not long term [Netherlands] and Iceland's data centers are booming—here's why that's a problem.

If you are interested in the essay on the environmental cost of online pornography that I mentioned in class, you can find it here. And a related piece in Vice.

Finally, many of the images of the IU data center that I showed in class came from this excellent walk-through by Matt Vukas, an IU computer science graduate and current Amazon employee. And here is the "Mr. Electricity" guide to how much electricity your personal computer uses.

III Water, water, everywhere ...

A typical data center requires hundreds of thousands of gallons of fresh water a day to operate; a single semiconductor fabrication facility requires millions.

Reading(s):

Hogan, Mél. 2015. "Data Flows and Water Woes: The Utah Data Center." *Big Data & Society* 2 (2): 1–12.

Christophe Lécuyer. 2017. "From Clean Rooms to Dirty Water: Labor, Semiconductor Firms, and the Struggle over Pollution and Workplace Hazards in Silicon Valley" [in en]. *Information & Culture: A Journal of History* 52 (3): 304–333

VIDEO: Explained | World's Water Crisis

VIDEO: Creating environmentally responsible data centers, conserving water

VIDEO: Intel's Fab 42: A Peek Inside One of the World's Most Advanced Factories

Supplementary Materials

For the long history of the relationship beween water and technology, at least in the United States, see Steinberg (2004) and Worster (1985). For a more theoretical perspective, the media theorist John Durham Peter's *The Marvelous Clouds: A Philosophy of Elemental Media* (Peters (2015)) is a sweeping and beautiful history of nature and media that encompasses whales, clocks, and data centers. An early talk he gave on the material that became his chapter on "God and Google" was the inspiration for my own research in this area. In recent years the energy, water, and environmental costs of the Cloud have attracted the attention of geographers, political scientists, historians, and engineers: Carruth (2014), Sanjeevi et al. (2015), Glanz (2012b), Amoore (2016), Hogan (2017), Mills (2013), Weiss (2007), and Greenberg et al. (2008).

IV The Global Lifecycle of Digital Goods

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. 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.

Reading(s):

Matthew N Eisler. 2017. "Exploding the Black Box: Personal Computing, the Notebook Battery Crisis, and Postindustrial Systems Thinking" [in en]. *Technol. Cult.* 58 (2): 368–391

ARTICLE: When Tesla Says It Recycles 100% of Its Batteries, What Does That Mean?

ARTICLE: The curse of 'white oil': electric vehicles' dirty secret ARTICLE: Why China Is Dominating Lithium-Ion Battery Production

ARTICLE:As Protests Mount Against San Cristóbal Silver Mine, Bolivia Looks to Extract Massive Lithium Reserves, But at What Cost?

Supplementary Materials

From lithium (Fletcher (2011) to tin (Ingulstad, Perchard, and Storli (2014)) to rare earth elements (Veronese (2015)), there is a growing literature on the essential elements of the digital economy. There is a related literature on the geopolitical, environmental, and security implications of this association with the extraction economy. See for example Bethel, Panama, and Luo (2010) and Jaffe (2011). By focusing on the material foundations of digital devices, the connection the digital and industrial economy becomes even more apparent. For some classic studies of pre-computer flows of material, see Sheller (2014), Robins (2011), and Mercury (2011).

V Containers

One of the ironies of the Information Age is that, despite the apparent shift in economic activity "from atoms to bits," human beings are now more dependent on ever on the physical transportation of materials. The rise of a massively integrated global shipping network is as much a story of computerization as it is of containerization.

Reading(s):

Joshua Ganz. 1995. "Inside the Black Box: A Look at the Container." *Prometheus* 13 (2): 169–183

ARTICLE: The Real Reason Coffee Has Gotten So Fancy

ARTICLE: The urgency of curbing pollution from ships, explained (Links to an external site.)

ARTICLE: Cargo ships are emitting boatloads of carbon, and nobody wants to take the blame (Links to an external site.)

VIDEO: CO2 On The High Seas (Links to an external site.)

Supplementary Materials

One of the paradoxes of the information age is that, counter to the predictions of tech enthusiasts such as Negroponte (1996) and Kelly (1999), digital technologies have not eliminated the need for the physical movement of materials and people, but have rather facilitated it. As **Ganz1995empty citation** suggests, the story of containerized shipping — arguably one of the greatest contributors to globalization — is essentially the story of the information systems that make the logistical management of containers possible.

The UCL Energy Institute commission an absolutely astonishing visualization of global shipping. The 30 day time-lapse video seen from the deck of a container ship can be found on Youtube.

On Wednesday I briefly discussed this article that attempted to measure the climate impact of online versus traditional retail in certain kinds of fast-moving goods (think bread and milk):

> Shahmohammadi, Sadegh, Zoran J. N. Steinmann, Lau Tambjerg, Patricia van Loon, J. M. Henry King, and Mark A. J. Huijbregts. 2020. "Comparative Greenhouse Gas Footprinting of Online versus Traditional Shopping for Fast-Moving Consumer Goods: A Stochastic Approach." *Environmental Science & Technology* 54 (6): 3499–3509.

VI Digital Residues

Information technologies often do not eliminate but only 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 environmental pollution associated with both the production and disposal of electronic goods. Both problems have been shifted to parts of the world — India, China, Africa — where environmental and worker-safety regulations are relatively lax. But even in the heart of Silicon Valley, the environmental consequences of computing can be long-lasting and deadly.

Reading(s):

McAllister L, Magee A, Hale B. "Women, e-waste, and technological solutions to climate change". *Health Hum Rights*. 2014 Jun 14;16(1):166-78.

Oteng-Ababio, Martin. 2012. "When Necessity Begets Ingenuity: E-Waste Scavenging as a Livelihood Strategy in Accra, Ghana." *African Studies Quarterly* 13 (1/2): 1–21.

Supplementary Materials

The public debate about the toxic effects of Silicon Valley semiconductor manufacturing begins in the 1980s (Bernstein et al. (1980) and Siegel and Markoff (1985)), diminishes with the move of such manufacturing abroad, and then resurges in the early 21st century (Gabrys (2013), Glanz (2012a), Adeola (2011), and Lepawsky (2015)). The literature on e-waste is refreshingly (or disturbingly, depending on whether you are thinking about it from a scholarly or environmental perspective), and includes not only Silicon Valley and Endicott, NY (Little (2014)) but also India (Jain and Chawla (2014)), China (Chiu (2011)), Africa (Oteng-Ababio (2012) and Grant and Oteng-Ababio (2012)), Taiwan (Chiu (2011)), and Bangladesh (Lepawsky and Billah (2011)), among other regions.

VII Maintain, Reuse, Recycle

In the United States, digital devices are assumed to be ephemeral, useful only until the next upgrade cycle. But in other parts of the world, users are much more resourceful about reusing and recycling these devices. The short lifespan of most consumer electronics in the Western world is not only a product of their design, but also a product of legal, economic, and political developments.

Reading(s):

Steven Jackson, Alex Pompe, Gabriel Kreishok. 2012. "Repair Worlds: Maintenance, Repair, and ICT for Development in Rural Namibia." *CSCW*

ARTICLE: How We Think about E-Waste Is in Need of Repair

VIDEO: 2nd Hand Phones and Spare parts Market | Longsheng Communications Market |Shenzhen | China

VIDEO: Do You Have a Right To Repair Your Phone? The Fight Between Big Tech and Consumers

Supplementary Materials

In the past few years the study of maintenance — as opposed to innovation — has reinvigorated technology studies (Ferguson (2016), McCray (2018), and Russell and Vinsel (2018)). This move is closely associated with the increased focus on infrastructures, which require constant maintenance. This includes information infrastructures (including software, which is often regarded as immaterial; see Parikh (1984), C. Edwards (1984), and Ensmenger (2009)). Closely associated with the work of maintenance is repair, which is of particular concern to scholars studying e-waste (Jackson, Pompe, and Krieshok (2012), Rosner and Ames (2013), and Koebler (2017)).

VIDEO: The dark side of electronic waste recycling
VIDEO: ToxiCity: life at Agbobloshie, the world's largest e-waste dump in Ghana.

If you are interested the right to repair as it relates to farm equipment, you might find Tractor Hacking: The Farmers Breaking Big Tech's Repair Monopoly to be a useful resource.

VIII Simulation & Surveillance

The use of computing devices to "see," measure, and represent the physical world has a long history. Indeed, most of what we know about climate change is the result of complex (and energy-intensive) computer simulation. Many of the sciences most essential to understanding the environment — from ecology to meteorology to genomics — are essentially computational.

Reading(s):

Edwards, Paul N. 1999. "Global Climate Science, Uncertainty and Politics: Data-laden Models, Model-filtered Data." *Science as Culture* 8 (4): 437–72.

Jennifer Gabrys et al. 2012. "Sensing an experimental forest: processing environments and distributing relations." *Computational Culture* 2

Supplementary Materials

Edward's *Vast Machine* [P. N. Edwards (2010)] is a masterwork in science studies, history of computing, and infrastructure studies. The article we are reading for this week is a concise introduction to this work.

IX The World is(in) a Computer

How have the new ways in which information and computing technologies allowed us to "experience" the world changed the way we think about our relationship to our environment? From virtual zoos to GPS-enabled adventure travel, digital devices are part of the complex ways in which humans have always used technology to mediate their relationship with the "natural" world.

Reading(s):

Peirce Caudell, A.B. (2021) A Lively Boundary: Children's Perspectives on Technology, Nature and How They Relate. PhD dissertation, Indiana University, Informatics department. Selected chapters.

ARTICLE: The Nemofication of Nature: Animals, Artificiality, and Affect at Disney World.

Supplementary Materials

Although many of the readings for this course focus on the costs and potentially negative consequences of computing (or if not negative, at least negative in contrast to prevailing ahistorical utopianism that pervades much of tech culture), it is important to note than an environmental historical approach to computing is not essentially concerned with making value judgments or advocating for change. The goal is to understand the mutually constructive interrelationship of nature and society. And there is no question that computational techniques and technologies have radically changed the ways humans perceive and interact with their environment, from meteorology (Nebeker (1995), Fleming (2011), and Harper (2011)) to ecology (Kingsland (1998), Hammond (1997), and Turnbull (2018)) to biology (Kay (2001), Johnston (2010), Helmreich (2007), and Emmeche (1994)) to geology (Carter et al. (2000) and Özkaya (1991)).

X Hey! That Elephant Has a Cell Phone…

Computers and other ICTs have greatly enhanced the ability of environmentalists and activists to interact with the natural world. Many of these developments have been positive and productive, and indicative of new modes of interaction between humans and non-humans.

Reading(s):

M D Graham et al. 2009. "The movement of African elephants in a human-dominated land-use mosaic" [in en]. *Anim. Conserv.* 12, no. 5 (October): 445–455

Sunyoung Kim et al. 2011. "Creek watch: pairing usefulness and usability for successful citizen science." In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems,* 2125–2134. CHI '11. Vancouver, BC, Canada: Association for Computing Machinery, May

VIDEO: Living with Elephants

VIDEO: Human-Elephant conflict: Can we coexist in peace?

Supplementary Materials

I have tried to resist the temptation to share a lot of "cute" videos in this (semi)-online course, but this one is both fun and relevant: Adorable Baby Elephant Tries To Steal Mobile Phone

XI Back to the Future

There is a close but complicated relationship between the counter-cultures that produced both the Internet and the modern environmental movement. But the vision of techno-utopian culture that came to dominant Silicon Valley was/is not the only model of a post- or non-industrial society. In this week, we will explore alternative "social imaginaries" that define new relationships between technology and environment, with a particular focus on the Afro-futurist movement of the mid-to-late 20th century.

Reading(s):

Rayvon Fouche. 2006. "The Wretched of the Gulf: Racism, Technological Dramas, and Black Politics of Technology." *Black Scholar* 36 (4)

VIDEO: Afrofuturism Explained: Not Just Black Sci-Fi

ARTICLE: How Afrofuturism Can Help the World Mend

ARTICLE: 'Wakanda Doesn't Have Suburbs': How Movies Like Black Panther Could Help Us Save the Planet

ARTICLE: Wakanda Forever: Anticolonialism as Sustainable Technology

ARTICLE: Digital colonialism is threatening the Global South

Supplementary Materials

Perhaps the most familiar example of Afro-futurist art in recent memory is the 2018 film *Black Panther*. The mythical king of Wakanda, T'Challa, debuted in a 1966 issue of the comic book *Fantastic Four*. There have been many iterations of this character that have appeared since then, including most famously the 2016 series authored by Ta-Nehisi Coates.

For an historically-grounded perspective on the Black Panther that speaks to contemporary developments related to our Week 4 conversation about cobalt and the Democratic Republic of Congo, see this wonderful article by Thomas McDow: Black Panther's Wakanda has historical roots in nuclear-age Congo.

For other classics of Afro-futurist art, see Samuel Delaney, *The Einstein Intersection* (Ace Books, 1967); Octavia Butler, *Blood Child* Four Walls Eight Windows Press, 1995; Beyonce, Black is King;

XII Sustainable Digital Design

Like all technologies, "the Cloud" as it is currently configured is the product of human imagination, guided and constrained by history and society. There is a growing movement with ICT design to take seriously questions of environmental sustainability, labor equity, and global justice, and we will close by contemplating the possibilites of such designs.

Reading(s):

Preist, Chris, Daniel Schien, and Eli Blevis. 2016. "Understanding and Mitigating the Effects of Device and Cloud Service Design Decisions on the Environmental Footprint of Digital Infrastructure." In emphProceedings of the 2016 CHI Conference , 1324–37. ACM Press.

International Telecommunication Union, *Toolkit on environmental sustainability for the ICT* (2012). ITU. Available online

XIII The Big Finish

Student projects and concluding remarks.

Reference Bibliography

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Amoore, Louise. 2016. "Cloud Geographies: Computing, Data, Sovereignty." *Progress in Human Geography* (August 11, 2016): 030913251666214.

Berkhout, Frans, and Julia Hertin. 2004. "De-Materialising and Re-Materialising: Digital Technologies and the Environment." *Futures* 36, no. 8 (October): 903–920.

Bernstein, Alan, Bob DeGrasse, Rachael Grossman, Chris Paine, and Lenny Siegel. 1980. "Silicon Valley: Paradise or Paradox." In *Mexican Women in the United States.* Chicano Studies Research Center Publications, January.

Bethel, Erik, Juan Andres Panama, and Sam Luo. 2010. "Is Lithium the 21 St Century's Oil?" *Part II. Seeking Alpha.*

Blum, Andrew. 2013. *Tubes: A Journey to the Center of the Internet.* First Ecco paperback edition. New York: Ecco.

Carruth, A. 2014. "The Digital Cloud and the Micropolitics of Energy." *Public Culture* 26 (2 73 2014): 339–364.

Carse, Ashley, and Joshua A Lewis. 2017. "Toward a Political Ecology of Infrastructure Standards: Or, How to Think about Ships, Waterways, Sediment, and Communities Together." *Environment and Planning A* 49, no. 1 (January): 9–28.

Carter, B. J., J. Desroches, A. R. Ingraffea, and P. A. Wawrzynek. 2000. "Simulating Fully 3D Hydraulic Fracturing." *Modeling in geomechanics* 200:525–557.

Chiu, Hua-Mei. 2011. "The Dark Side of Silicon Island: High-Tech Pollution and the Environmental Movement in Taiwan." *Capitalism Nature Socialism* 22, no. 1 (March): 40–57.

Edwards, Chris. 1984. "Information Systems Maintenance: An Integrated Perspective." *MIS Quarterly* 8:237.

Edwards, P N. 2010. *A Vast Machine: Computer Models, Climate Data, and the Politics of Global Warming.* Cambridge, Mass: MIT Press.

Eisler, Matthew N. 2017. "Exploding the Black Box: Personal Computing, the Notebook Battery Crisis, and Postindustrial Systems Thinking" [in en]. *Technol. Cult.* 58 (2): 368–391.

Emmeche, Claus. 1994. "The Computational Notion of Life." *Theoria: An International Journal for Theory, History and Foundations of Science* 9 (21): 1–30.

Ensmenger, Nathan. 2009. "Software as History Embodied." *Annals of the History of Computing, IEEE* 31, no. 1 (January 1, 2009): 88–91.

———. 2018. "The Environmental History of Computing" [in en]. *Technol. Cult.* 59 (4S): S7–S33.

———. 2021. "The Cloud is a Factory." In *Your Computer is on Fire,* edited by Thomas S Mullaney, Benjamin Peters, Mar Hicks, and Kavita Philip, 29–50. MIT Press.

Ferguson, David. 2016. "We Love 'Disruptors'. But It's Regular People Who Keep the World Afloat." *The Guardian: Opinion,* April 16, 2016.

Fleming, James Rodger. 2011. *Fixing the Sky: The Checkered History of Weather and Climate Control.* Columbia University Press, December.

Fletcher, Seth. 2011. *Bottled Lightning: Superbatteries, Electric Cars, and the New Lithium Economy.* First Edition edition. New York: Hill and Wang, May 10, 2011.

Fouche, Rayvon. 2006. "The Wretched of the Gulf: Racism, Technological Dramas, and Black Politics of Technology." *Black Scholar* 36 (4).

Gabrys, Jennifer, et al. 2012. "Sensing an experimental forest: processing environments and distributing relations." *Computational Culture* 2.

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Ganz, Joshua. 1995. "Inside the Black Box: A Look at the Container." *Prometheus* 13 (2): 169–183.

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———. 2012b. "THE CLOUD FACTORIES: Data Barns in a Farm Town, Gobbling Power and Flexing Muscle." *New York Times* (September).

Graham, M D, I Douglas-Hamilton, W M Adams, and P C Lee. 2009. "The movement of African elephants in a human-dominated land-use mosaic" [in en]. *Anim. Conserv.* 12, no. 5 (October): 445–455.

Grant, Richard, and Martin Oteng-Ababio. 2012. "Mapping the Invisible and Real "African" Economy: Urban E-Waste Circuitry." *Urban Geography* 33, no. 1 (January): 1–21.

Greenberg, Albert, James Hamilton, David A. Maltz, and Parveen Patel. 2008. "The Cost of a Cloud: Research Problems in Data Center Networks." *ACM SIGCOMM computer communication review* 39 (1): 68–73.

Hammond, Debora. 1997. "Ecology and Ideology in the General Systems Community." *Environment and History* 3 (2): 197–207.

Harper, Kristine C. 2011. *Weather by the Numbers.* The Genesis of Modern Meteorology. Mit Press, December.

Hecht, Jeff. 2004. *City of Light: The Story of Fiber Optics.* City of Light. Oxford University Press.

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Hogan, Mél. 2017. "(Another) Battle in the Clouds." *The Goose* 16 (1): 26.

Ingulstad, Mats, Andrew Perchard, and Espen Storli. 2014. *Tin and Global Capitalism, 1850-2000: A History of "the Devil's Metal".* Routledge, September 4, 2014.

Jackson, Steven J., Alex Pompe, and Gabriel Krieshok. 2012. "Repair Worlds: Maintenance, Repair, and ICT for Development in Rural Namibia." Proceedings of the ACM 2012 Conference on Computer Supported Cooperative Work.

Jaffe, Robert. 2011. *Energy Critical Elements.* APS PANEL ON PUBLIC AFFAIRS & THE MATERIALS RESEARCH SOCIETY.

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Kay, Lily E. 2001. *Who Wrote the Book Life?: A History of the Genetic Code.* OCLC: 750690758. Stanford, Calif.: Stanford University Press.

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Koebler, Jason. 2017. "Why American Farmers Are Hacking Their Tractors With Ukrainian Firmware," March 21, 2017.

Lécuyer, Christophe. 2017. "From Clean Rooms to Dirty Water: Labor, Semiconductor Firms, and the Struggle over Pollution and Workplace Hazards in Silicon Valley" [in en]. *Information & Culture: A Journal of History* 52 (3): 304–333.

Lepawsky, Josh. 2015. "The Changing Geography of Global Trade in Electronic Discards: Time to Rethink the e-Waste Problem: The Changing Geography of Global Trade in Electronic Discards." *The Geographical Journal* 181, no. 2 (June): 147–159.

Lepawsky, Josh, and Mostaem Billah. 2011. "Making Chains That (Un) Make Things: Waste–Value Relations and the Bangladeshi Rubbish Electronics Industry." *Geografiska Annaler: Series B, Human Geography* 93 (2): 121–139.

Little, Peter C. 2014. *Toxic Town.* IBM, Pollution, and Industrial Risks. NYU Press, March.

McCray, Patrick. 2018. "Most of the Time, Innovators Don't Move Fast and Break Things," August 13, 2018.

Mercury, Mining. 2011. *Empire: The Human and Ecological Cost of Colonial Silver Mining in the Andes.* Bloomington: Indiana University Press.

Mills, Mark. 2013. *The Cloud Begins With Coal: Big Data, Big Networks, Big Infrastructure, And Big Power An Overview Of The Electricity Used By The Global Digital Ecosystem.*

Müller, Simone. 2016. *Wiring the World.* The Social and Cultural Creation of Global Telegraph Networks. Columbia University Press, April.

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Oteng-Ababio, Martin. 2012. "When Necessity Begets Ingenuity: E-Waste Scavenging as a Livelihood Strategy in Accra, Ghana." *African Studies Quarterly* 13 (1/2): 1.

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Peters, John Durham. 2015. *The Marvelous Clouds.* University of Chicago Press, June.

Robins, Nicholas A. 2011. *Mercury, Mining, and Empire the Human and Ecological Cost of Colonial Silver Mining in the Andes.* OCLC: 840850483. Bloomington: Indiana University Press.

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Russell, Andrew, and Lee Vinsel. 2018. "Innovation Is Overvalued. Maintenance Often Matters More," August 13, 2018.

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