

Understanding ‘How Computing has Changed the World’

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Abstract: How can we address the history of computing in satisfying detail, recognizing that computing artifacts and practices are often shaped by local circumstances and distinct cultures, and yet have our accounts also capture the longer term processes in which computing has certainly shaped the world? This article reviews three traditions of scholarly work in the field; proposes a new line of scholarship that might integrate the local shaping with the wider processes; and concludes with some thoughts on collaborative, international, and interdisciplinary research programs to understand how and when and why computing has changed the world.

Keywords: history of computing; computers and society; digital computing; information age

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Everyone knows that “computing has changed the world,” but, strangely enough, our existing historiography of computing faces numerous difficulties in addressing this question directly. Examples and models for an historical understanding of this key question are surprisingly scarce.¹ I believe this is because historians’ disciplinary preferences for subject specificity and archival virtuosity have encouraged us to do detailed studies of individual machines, programs, and companies, and occasionally to examine the “social construction” of specific

computing technologies, but our focus on specifics has made it difficult to conceive and conduct the wide-ranging and long-duration studies that can show the longer-term consequences of technical changes for society, culture, economics and politics. I have suggested elsewhere that the “nature” of technologies—whether they seem to have impact on society and culture, or appear instead to reflect society and culture—depends crucially on the temporal and analytical scale of our inquiries, that is, whether we are looking at them closely with a fine-grained historical microscope or instead taking a wider or longer term view.² To take just one example, is Moore’s Law better understood as an irresistible agent of change—an instance of “raw technological determinism” as Paul Ceruzzi recently asserted—or rather as a contingent and constructed entity, as Ethan Mollick suggests?³ Of course microscopes and telescopes each can tell us something about the natural world, even if the views are quite distinct and by themselves partial and necessarily incomplete. How might we develop new modes of analysis and explanation that will address the history of computing in satisfying detail, recognizing that computing practices are often shaped by local circumstances and distinct cultures, and yet capture wider or longer term processes where computing has manifestly shaped the world? This paper first reviews three thematic traditions of scholarship in history of computing; it then proposes a new line of scholarship to understanding how computing has changed the world; it concludes with some thoughts on collaborative, international, and interdisciplinary research programs to understand how and when and why this came about.⁴

Very roughly, the history of computing has progressed through three distinct thematic traditions in the past quarter century or so. First, in an early, machine-centered phase, computer historians and leading practitioners (they were sometimes one and the same person) debated the priority and internal functioning of certain key electronic digital machines at both hardware and software levels. Next, the first generation of professional historians of computing traced the varied roots of the information age. Most recently, historians have directed attention to the institutional context of computing. Of course, many people remain interested in hardware, software, information, and institutions. Clearly these thematic traditions are healthy and can be extended with future research.⁵

The new line of research outlined here, while drawing on this work, proposes that we shift to focus on the interaction of computing—including hardware, software, and institutional

dimensions—with large-scale transformations in economies, cultures, and societies. Citizens and policymakers know that computing has changed the world, and historians of computing should take a more prominent role in helping understand this history. I cannot think of a more pressing charge for the next generation of our work. Such a project may also help overcome the Anglo-American bias that persists in much of the current literature.⁶ All societies today have a relationship with computing, not only those that have ‘pioneered’ computing or even those labeled as early or late adopters. In today’s global economy, a country or region that might entirely lack access to computing still has a relationship with the computer-mediated global economy through trade and travel, even if it is entirely frozen out of such trade. (One might imagine an “island” somewhere that is entirely “off the net” and with no computing whatsoever, but to my mind this special situation resembles David Nye’s conception of “wilderness” in contemporary America: a specific and delimited part of society or culture deliberately held apart from the mainstream. Just as Nye insists that wilderness is a part of mainstream urban-technological society, owing at minimum to the need to maintain physical and legal boundaries between them, so too would this hypothetical computer-free island have a boundary relationship with the wider world where computing is more or less pervasive.⁷) Indeed, it may be crucial to understand just those countries, regions, or cultures that partially or wholly lack access to first-world computing. The terms digital divide, E-junk, and digital dumping flag these latter phenomena.

Thematic Traditions

The first thematic tradition in the history of computing took form with questions posed by practitioners and pioneers of digital computing. Their key questions directed scholars to identify the “first” digital computers, and to understand the technical details of how they worked. It was simply assumed that “the computer” that mattered was the electronic digital computer, its immediate predecessors and obvious offspring; overlooked in this early literature was that “the computer” was for many decades a person, often a woman, doing numerical calculations of great complexity.⁸ In round terms the narrative of significant machines, concepts, and pioneers began with one of the several World War II-spawned machines (Manchester, Enigma, Atlas, ENIAC, or Whirlwind), untangled the genesis of the

stored-program concept, and marched forward to UNIVAC and perhaps crested with IBM's conquest of the world. Early numbers of the *Annals of the History of Computing* record the several priority debates; Emerson Pugh's several books on IBM continued this tradition;⁹ and volumes right down to the present have echoed these weighty matters, including most explicitly Alice Burks' *Who Invented the Computer? The Legal Battle That Changed Computing History*.¹⁰

Michael Mahoney provided an early critique of this tradition as "insider history." Among the problems he identified were the distinct preference for pinning down "facts and firsts" as compared with the understanding of historical context; a recitation of "technical givens" versus a recognition of actors' historical uncertainty and the difficult choices they faced; and a preference for "vivid anecdotes" over the cultivation of context and perspective. With a focus on the details of computing technology, these accounts do not give an assessment of the social, economic, cultural changes that computers were presumed to bring about.¹¹ Accordingly, while these works are clearly valuable in documenting what when on, they are of limited help in addressing the question of 'how computing changed the world.'

For instance, the coming of 'the digital' was no mere technical advance but also an important cultural shift within the technical community. Early historical work on the electronic digital computer entirely ignored the alternate tradition of computation for fire control and the vibrant world of analog computing, recently explored by James Small and David Mindell and further anatomized in a number of recent articles in *Annals of the History of Computing*.¹² Problematizing the coming of 'the digital' has been another rewarding and insightful approach. In prize-winning articles, Larry Owens drew attention to MIT's rich tradition in analog computing from the 1920s and also provided a sharp cultural analysis of the sea-change from analog to digital computing at MIT during and after the war years.¹³ Owens corrects the common perception that the way forward into the digital future was clear and uncontested. Accordingly, he makes an important step is seeing the history of computing as the history of cultural change.

A contextual technical history—devoting close attention to the specific details of the machines while situating them in their historical context—should be a vital on-going tradition. Recall the classic passage in Tracy Kidder's *Soul of a New Machine* describing the 27 printed-

circuit boards constituting a VAX minicomputer and positing the useful theory, whether strictly speaking true or not, that “VAX embodied flaws in DEC’s corporate organization.” Both were too complex and hierarchical, according to the account’s protagonist. Kidder proposed that the architecture of the computer was a mirror of the architecture of the company. Not all such readings of course will find a one-to-one correspondence between the technical details and anything else, whether corporate structure or social structure. Donald MacKenzie finds consequential drama in the minutia of hardware (there is a riveting story to how Intel’s i8087 floating point coprocessor handles extremely small ‘denormalized’ numbers) and a full-scale tragedy in the apparently mundane, but literally deadly, software-timing errors in the Patriot air-defense missile.¹⁴ Lawrence Lessig, Jay Kesan, and other legal scholars are devoting attention to understanding how “code is law.”¹⁵ Clearly, we need more such hardware and software histories attentive to technical details and aware of their wider social, political, and legal implications and meanings.

A second thematic tradition in the history of computing shifted focus to the historical roots of the “information age.” A self-described band of ‘colonizers’ including historians William Aspray, Martin Campbell-Kelly, and Paul Ceruzzi asked a new set of questions, which pivoted on the genesis of the information age. In his essay “The History of the History of Computing,” Campbell-Kelly wrote that “Professionals and colonizers emerged in the 1980s We have become colonists, in the sense of staking a claim for the history of computing to be recognized as a valid historical enterprise. This has involved establishing the usual trappings of academic recognition: a scholarly journal, monographs, conferences, research centers, museums, PhD programmes, and undergraduate courses.”¹⁶ In this information-age view computers were machines that first and foremost processed information and only secondarily provided the functions of calculation, control, or communication. Numerous landmark volumes published in the 1990s prominently developed this theme including Campbell-Kelly and Aspray’s *Computer: A History of the Information Machine*; Chandler and Cortada’s *A Nation Transformed by Information*; and Manuel Castells’ *Information Age* trilogy. Ceruzzi framed his *History of Modern Computing* around the transformation of “the mathematical engines of the 1940s to the networked information appliance of the 1990s.” Even Riordan and Hoddeson’s tightly focused history of the

transistor at Bell Laboratories was subtitled, somewhat grandly, *The Birth of the Information Age*.¹⁷

Attention to electronic digital machines did not disappear in these information-age accounts, of course, but the focus expanded to a broader set of technologies and to the use of these machines in insurance, finance, and government. Earlier counting and tabulating machines that processed information mechanically or electromechanically commanded new attention and respect. It became clear that at least 15 years before the emergence of the electronic digital computer an entire technical infrastructure of data processing was in place and already thoroughly embedded in business and government routines. In 1933 IBM offered 17 different types of key punches, in various mechanical and electric configurations, for 34-, 45-, and 80-column cards; 5 distinct sorting machines and 9 different tabulators, each available in multiple models and for different-width punched cards; while in the same decade Burroughs created an entire suite of mechanical bookkeeping and accounting machines.¹⁸ On reflection, it was indeed no accident that the office machine giants of the 1920s—IBM, Burroughs, NCR, and Remington Rand—became early leaders in the postwar computer industry.

The theme of information and society shows ample signs of continued interest and conceptual innovation. Recent works here include Jon Agar's *The Government Machine*, Martin Campbell-Kelly's pioneering book-length study of the software industry, and JoAnne Yates' *Structuring the Information Age* (2005).¹⁹ Agar's work especially breaks new methodological ground, providing an extended evaluation of the computer as "a materialization of bureaucratic action" (p. 391) with wide-ranging examples drawn from the nineteenth-century British Civil Service, turn-of-century statistical reformers, and post-1945 welfare state. Agar surveys the cryptography, radar-based air defense, social-statistical surveys and national registry, as well as the wartime logistics, personnel records, and operations research of the Second World War, and aptly calls it an "information war." Each of these works, in providing a benchmark to evaluate a major social, economic and political change (the coming of the information age), are obviously promising in the effort to understand 'how computing changed the world'.

A third thematic tradition—in addition to the pioneering machines and the information age—can be discerned with the work of historians who take up the question “how did (certain) institutions shape computing?” This is a pronounced shift in emphasis, if not an entirely novel dimension. These accounts move to the background their treatment of individual computing machines or the contours of the information society, foregrounding instead the governmental, engineering, or corporate institutions that brought them about. The U.S. military services, the National Science Foundation, and IBM have received particular attention. Among exemplary works in this tradition I would number Arthur Norberg and Judy O’Neill’s institutional study of the wide-ranging ARPA initiatives in computing; Donald MacKenzie’s studies of supercomputing; Janet Abbate’s *Inventing the Internet*; Alex Roland’s critical evaluation of *Strategic Computing*; and Steve Usselman’s work on business strategies and learning processes within IBM.²⁰

In different ways, these studies each place the story of the technical developments in computing squarely into the context of institutions. Institutional dynamics—that is, the specific situated context of decision-making that exists within a complex organization such as DARPA or IBM—are just as important here as engineers drawing circuit diagrams or executives debating corporate strategy. To some extent, this literature obviously draws on earlier studies of the federal government’s role in computing by Kenneth Flamm as well as the more recent NRC report *Funding a Revolution*.²¹ Yet what distinguishes this newer institutional literature, I believe, is explicit attention not only to the “rate” of technical change but also to its “direction.”²² These studies largely accept the proposition that directed institutional sponsorship sped up the pace of computing developments; in addition they often grapple with the question of what difference did such institutional sponsorship make in the shaping and direction of computing developments? Considering the multiple potential lines of hardware or software development that were possible at some time, these authors ask how institutional dynamics influenced the actual developments in favor of one potential outcome or another. If the older studies were strong on description, these studies move more assertively to analysis of how and why certain paths were chosen as well as how and why certain results came to be—while others did not.²³

A Tradition to be Made?

For a fourth thematic cluster, clearly not yet a “tradition,” I can tentatively suggest three characteristics. Recognition of them will help historians of computing to better tackle the question of how computing has changed the world and at the same time connect our field to other scholarly concerns. In this fourth cluster, I believe history of computing will be a “hybrid” field, increasingly drawing on diverse disciplines and methods. I hope our field will take up the challenge of comprehending the twin-fold shaping of computing and society. And to do so, I suggest we engage in studies that situate computing within major historical transformations. If we believe that computing has changed the world, this is what we should study.

First, what might the history of computing look like as a “hybrid” field? I think that scholarly work in humanities and social sciences frequently exhibits a version of “hybrid vigor,” in which a core field or discipline is invigorated through exchange with neighboring fields or disciplines. Conversely, fields that too narrowly define their core concerns are at risk of being cut off from broader scholarly debates. Sometimes a dominant method or influential paradigm has the effect of consolidating a field around a set of key questions, with the attendant risk that the field can become isolated if no one else finds these questions to be compelling ones. As instances I would point out that business history, history of technology, and philosophy of technology have all, in the past, flirted with this unhealthy isolation. Each has substantially revived in no small measure due to sustained interactions with neighboring disciplines. Philosophers of technology have engaged with sociology and politics, while business and technology historians have sought new inspiration in studies of consumption, identity, gender and politics. Each of these three fields is certainly less “focused on core questions” than it was two decades ago, but all are the more interesting for it and indeed show many indications of hybrid vigor.

In my view, historians of computing can confidently be looking outward to neighboring fields and disciplines for conceptual inspiration as well as new audiences. Let me make a couple suggestions. In conceptualizing studies dealing with computing artifacts, computing systems, and their interactions with society and culture, there are obvious overlaps

with the concerns of historians of technology who have been studying diverse artifacts and systems as well as their interactions with culture.²⁴ Historians of computing studying companies, corporate culture, and various levels of industries are finding common cause with business and economic historians as they examine organizations, learning processes, and the flows of information.²⁵ At present both business history and history of technology are themselves hybrid fields, with multiple productive and inspiring overlaps with historians of labor, gender, culture, and consumption. Histories of labor, gender, and consumption have yet to make a significant interaction with the history of computing, despite several suggestive articles pointing the way.²⁶ Historians of computing seem ideally positioned for evaluating and extending the rich bodies of theorizing coming from organizational theory and evolutionary and institutional economics.²⁷ Historians of science have been somewhat less avid for cross-field interactions, but studies of computer science as an academic discipline have much to learn from them, as do studies of professionalization in the diverse forms from data processing to software engineering.²⁸

There is a second way in which history of computing will become a hybrid field. The historians of science, technology, medicine, and business who recognize that computers have become vital infrastructures that constrain and enable intellectual and institutional developments in their chosen fields of study will in effect become historians of computing. Even though the list of promising topics here could be extended nearly without limit, think about just such instances as the impact of computing on chemistry, physics, biology, and the atmospheric sciences;²⁹ medical informatics in its several incarnations; and the entire information infrastructure of modern business from financial transactions to point-of-sale terminals or from supply chains to value chains. We also need more historical studies of the entire e-revolution in government policies and practices.

Second, to fully engage the question how computing has changed the world, we need to craft new and embracing narratives that adopt a twin-fold analytical goal. For some time, I have tried to understand (to introduce a bit of jargon) the social shaping of technology as well as the technological shaping of society.³⁰ Understanding both of these will help in understanding how computing has changed the world. On the one hand, we need to show how developments in computing shaped major historical transformations, that is, how the evolution of computing was consequential for the transformations in work routines, business

processes, government activities, cultural formations, and the myriad activities of daily life. It may be a commonplace that computing in some way led to the “information revolution” but I would like to know more deeply as well as more precisely how computing in its various forms and manifestations influenced the “rate and direction” (to take a term from early evolutionary economics) of these social, cultural and economic transformations. What specific characteristics of the information age can we trace to the proliferation of computers (or other technical practices), and which characteristics of highly bureaucratized societies were merely enhanced by the availability of computing? After all, standardized and routinized forms of “information” as a key aspect of society long predates the emergence of analog or digital computers in the 20th century, with the essays in Chandler and Cortada making an impressive case for the 19th century and Headrick’s *When Information Came of Age* making a spirited case for the 18th century.³¹ What is distinctive about these varied historical manifestations of the information age? How did they come about? Could the present-day computer-saturated information age have been different? And then there is the question that results when we use the tools of history to think about the present and the future.³² What possibilities exist for using the evolutions in computing theories and practices to shape future social, cultural, political and economic developments? At the very least, think about the cultural enthusiasms behind Unix, personal computing, or the open source movement, which each drew inspiration from some notion that this was the way to change history.

At the same time, I think our narratives and analysis should show how major historical transformations shaped the evolution of computing. We know that the office machine giants in the U.S. were a key locus of innovation in information, data processing, and digital computing. Yet, how did the specific institutional context—here, commercial information processing—influence the varieties of hardware, software, systems and services that emerged. Using evolutionary language, we can ask what were the successful variants, and how and why were these selected over the unsuccessful ones. The latter are all-too-often simply written off as inferior, as if latter-day criteria were clear at the time, or entirely forgotten.³³

In the U.S. the military was a pervasive influence on many sectors of computing through the long decades of the Cold War.³⁴ In *The Closed World*, Paul Edwards begins to evaluate the impact of the Cold War on the character of computing, finding that a preference for closed-world structures and practices suffused military institutions and computer designs.

Yet pervasive does not imply omniscient or deterministic. Donald MacKenzie's essay "Influence of the Los Alamos and Livermore National Labs on Supercomputing" shows that the assessment of institutional influence may be complex and yet compelling: while the computational needs of nuclear weapons designers were indeed paramount in supercomputing, their specific technical requirements—deterministic, number-crunching, mesh computation versus probabilistic, multiple-branch, Monte Carlo techniques—sent a generation of high-performance computing in at least two directions, not down a single path. And the specific institutional context of DARPA's relations to computing, where leading figures from within academic computing were placed in charge of relatively large pools of military research funds, meant that purely "military" and purely "academic" influences may never be neatly separated.³⁵

Perhaps the largest and most pervasive institution in computing, although it stretches the term, is the high-technology environment of California's Santa Clara County, better known as Silicon Valley. A spate of recent studies has amplified the basic findings of AnnaLee Saxenian's now-classic *Regional Advantage: Culture and Competition in Silicon Valley and Route 128*, which emphasized risk-taking, entrepreneurship, and networks of innovative companies.³⁶ Stuart Leslie and Rebecca Lowen deal with the interactions of high-technology innovation and military research sponsorship at MIT and Stanford. Ross Bassett, in his *To the Digital Age*, gives a close technical history of the now-pervasive MOS semiconductor technology. And two recently published studies give distinct interpretations of Silicon Valley, with Leslie Berlin focusing on the contributions of Robert Noyce while Christophe Lécuyer emphasizes instead the valley's longer history and its firms' ability to master the manufacturing of vacuum tubes forward to semiconductors.³⁷

In *analyzing* why certain events in computing as well as broader processes in society, politics and culture unfolded in the way they did, and not in some other way, international studies and comparative studies will be crucial. It is a common practice in assessing influence to begin with some given institution or initiating event and then "read forward" the consequent developments, tracing (so it appears) the influence of the institution or event. A generation of technology assessment exercises attempted to read off the impacts of a given technology in this way. The NSF-funded TRACES study in the late 1960s claimed to show the influence of basic research on technological innovation. Assessments of the military's

role in computing often operate in a similar fashion. Vernon Ruttan's recent historical analysis of six general-purpose technologies, including semiconductors and computers, amasses impressive evidence that the U.S. military services played an important role in fostering the development of technology.³⁸ Yet in reading forward from the U.S. military's initiating role during the Cold War decades, he might overestimate the military's influence, substantial though it was, as a force in technology development. (Such a retrospective method of "reading forward" from case studies of success has a number of inherent biases, such as underestimating the complexity and uncertainty of the innovation process as well as obscuring the presence of blind alleys or dead ends in research and innovation.) A comparative analysis of Japan tells a different story: there private companies worked in concert with the long-fabled "guidance" from the civilian bureaucrats at MITI, with little or no overt military influence, to build up world-beating capabilities in consumer electronics, semiconductors, and certain classes of computers. Whether war is "necessary" (Ruttan's choice of word) for economic growth, then, seems to depend on whether your paradigm case is the U.S. or Japan.

Third, I am suggesting that we devote attention to situating our studies of computing *within* and as a vital part of major historical transformations. If computing has changed the world, surely this is a compelling site to investigate. Keeping in mind my second point above, what we need are studies that examine the two-way shaping or co-construction of computing alongside such major processes as globalization; the set of "e" institutions (e-commerce, e-government, e-education); and surveillance and privacy. Then there is the profound transformation of research practices: across the board, in industrial, academic, and governmental laboratories and research sites, computers have become not merely helpful research tools but a necessary infrastructure that researchers use in collecting, interpreting, and visualizing data as well as running the models that evaluate the data. Paul Edwards' studies of computing and global climate change are an extremely promising step in this direction.

This vision of studying computing in the context of broad historical transformations almost certainly entails drawing on a much wider set of research methods and archival materials than we have traditionally used. Revisit the birth of the information age, thinking about it as widely as you can. The traditional archival sources such as papers of leading

computer researchers, engineers, and entrepreneurs will of course remain important; oral histories and documents will certainly have their place. Still, understanding these wider problems and questions will require engagement with a diverse range of research materials (and, not coincidentally, diverse competences that researchers embracing diverse “hybrid” fields will gain access to). We will need business historians to help understand businesses as leading *users* of computers, a step taken by Jim Cortada’s *Digital Hand* trilogy as well as work by JoAnne Yates, Eric von Hippel, and others.³⁹ And we will need specialists in governmental records to probe the varied levels of government as leading users, too. Labor historians might study the untold legions of information-technology industry workers. Social historians might use census microdata to explore fine-grained patterns. And researchers attentive to rhetoric and popular culture will provide insight into cultural change.⁴⁰

Research for the Future

By way of a conclusion, I can outline three research programs that address the question of how computing has changed the world. Each of these is an actual project in some stage of development, some further along than others. Each of them situates the history of computing, including hardware, software, and institutional dimensions, squarely within broader social, economic, and political transformations. These involve Europe, Moore’s Law, and globalization, but surely there are many more such topics deserving our attention.

For Europeans, setting technical developments squarely in the context of on-going social, political, economic and cultural processes is simple: they face a new currency, new food standards, new flows of consumer goods and technologies, and many new and aspiring members to the European community. European integration was launched formally in the 1950s and gained significant force in the 1990s. With Dutch leadership a group of technology historians set up an international network called “Tensions of Europe,” with around 150 participants working in ten parallel research teams, to investigate the role of technology in the making of Europe across the 20th century. Research teams focused on varied sectors and aspects of this immensely complex history: cities, mobility, infrastructures, colonialism, consumption, communication, information, big engineering projects, agriculture and food.⁴¹

A follow-on project funded by the European Science Foundation is being organized under the banner “Inventing Europe,” and we hope that the history of computing will play a significant role.⁴² A group of leading European historians of computing, organized by Gerald Alberts, is exploring how Europe took shape through the dissemination and use of software. Multinational companies formed something like a pan-European information-technology network. Even though IBM was a U.S. company, its wide reach and standard-setting technology tended to bind European companies and business cultures together. What resulted, however, was not precisely a single corporate culture. IBM found that its technology and practices interacted with local cultures and expectations: in Finland IBM meant easy access to Western Europe, while in France and the Benelux countries IBM meant access to American culture, even if people traveled to Stuttgart to get it. In Zurich, the site of an important IBM research lab, IBM meant an international technology heavyweight, but not precisely an American one. IBM had surprising influence also in Eastern Europe, through the unauthorized duplication of its machines and their integration into the Soviet planning system. Another topic of interest is IFIP, founded in 1959 as an international forum for computer scientists, and its advocacy of the programming language ALGOL.

A second research program that addresses how computing has changed the world is one we are organizing at CBI on “Moore’s law.” Oddly enough, historians have only begun to examine Moore’s law.⁴³ It started out in 1965 as a simple observation by Gordon Moore, then working for Fairchild Semiconductor, that a certain class of integrated electronic components seemed to be doubling in density each one or two years. Over time, in a historical process that we should be able to analyze, Moore’s “law” became entrenched at Intel and then across the U.S. semiconductor industry (and in time internationally), became some sort of guiding light for venture capitalists, and eventually emerged as a staple of business journalists and popular culture. Far from its being “impervious to social, economic, or political contexts” (in Ceruzzi’s words), our preliminary research suggests that Moore’s law was thoroughly bound up with the semiconductor industry’s bid for favorable trade status as well as the hefty Defense-Department subsidy of SEMATECH (1987-96), a cross-industry R&D collaboration which set the institutional framework for the famous industry-wide “roadmapping” exercises. These took Moore’s law as an axiom, and provided a nation-wide (and in time international) mechanism that synchronized the R&D efforts of firms across the

industry—to keep pace with as well as to realize Moore’s law. Moore’s law also depended absolutely on the ability of electronics firms to mobilize sufficient capital to build the next generation of semiconductor “fabs,” which, for some years, also increased their costs (*pace* Moore’s law) in exponential fashion. Perhaps a bit tongue in cheek, this doubling in cost became known as “Rock’s law” after the pioneering venture capitalist Arthur Rock. In our study, we aim to understand Moore’s law as both an agent of change that shaped history as well as a contingent construction shaped by political and economic forces.

A third research program to understand how computing has changed the world would squarely address the process of globalization. Again, business journalists and popular writers have provided a clutch of generalizations and assertions—the death of distance, the world is flat, and many others—that need thorough and sustained historical evaluation. Clearly, fax machines, airplane reservation systems, networked computers, and many other computer-mediated forms of communication have something to do with globalization. Absent a network of computing, Federal Express and Airbus would each fall out of the skies, while just-in-time logistics would come to a grinding halt. But does this mean that computing, by itself, brought these developments about? A more nuanced approach to globalization and computing is provided by S.E. Goodman, writing in the *Communications of the ACM*, who notes the “very uneven” distribution of computing and telecommunications between countries: “what is there to compare between the semiconductor industries of Japan and Nigeria?”⁴⁴ There is moreover an important environmental history to computing and globalization. The United Nations Environment Program estimates that each year between 20 and 50 million tons of electronics are discarded, an unintended but nonetheless real consequence of Moore’s Law. At the port in Lagos, Nigeria, each month 500 40-foot containers arrive filled with obsolete computer components from the developed world, but up to three-quarters of the equipment is literally junk that is not even useful in the city’s active recycling market.⁴⁵ The contemporary debate about outsourcing is another topic needing further historical analysis.⁴⁶ We have a great deal of work to do. Look up “global” in the IEEE’s search tool for *Annals of the History of Computing*, and, apart from some book reviews, you get Jim Cortada’s programmatic essay, proposing a research agenda to investigate how computing went global.⁴⁷

In sum, a tremendously exciting era is opening up for historians of computing in the next quarter century or so. If I may hazard a few general predictions, it would be these. In the coming years we—both those writing for and those reading in *Annals of the History of Computing*—will be a larger group, and a more heterogeneous group than in the past quarter century. Historians of many specialties will inevitably see computing interacting with their chosen subject matter, and many of them will become at least part-time historians of computing. One sees early signs of this development even today: business and technology historians, as well as rhetoric and popular culture scholars, who might not consider themselves authentic card-carrying historians of computing are doing interesting work in the field. In addition, citizens and policymakers will certainly need historical perspective and practical insight into the world that has, to a significant extent, been shaped by the varied forms of computing—the entire array of machines of calculation, control, information, education, entertainment, communication, infrastructure. And I hope that historians of computing, however they arrive in the field, will be drawn into considering the big questions of historical transformation. If computing has changed the world, we have an immense opportunity, and also a significant responsibility, to help understand how this came about.

FOOTNOTES

¹ Authors such as Lewis Mumford, Thomas Hughes, Alfred Chandler, James Beniger, David Nye, and others have provided insight into technology's interactions with society, culture, and institutions, but they have not typically done extensive historical analysis of computing; nonetheless, see the Hughes volume (*Systems, Experts, and Computers*) and the Chandler and Cortada volume (*Nation Transformed by Information*) cited below. Sociologist Manuel Castells, in his *Information Age* trilogy (Blackwell 1996-98), relates changes in information technology to general patterns in society and culture, such as globalization, but at a rather high level of generalization.

² Thomas J. Misa, "Retrieving Sociotechnical Change from Technological Determinism," in Merritt Roe Smith and Leo Marx, eds., *Does Technology Drive History?* (Cambridge: MIT Press, 1994), pp. 115-41; idem, "Findings Follow Framings: Navigating the Empirical Turn," *Synthese* (forthcoming).

³ Paul E. Ceruzzi, "Moore's Law and Technological Determinism," *Technology and Culture* 46 no. 3 (2005): 584-593, quote on p. 593; Ethan Mollick, "Establishing Moore's Law," *IEEE Annals of the History of Computing* 28 no. 3 (2006): 62-75.

⁴ A good place to start are the chapters by Bruce Lewenstein, David Cantor, Lillian Hoddeson, and Arne Hessenbruch (on archiving, commissioned histories, oral histories, and collaborations with working scientists, respectively) in Ronald E. Doel and Thomas Söderqvist, eds., *The Historiography of Contemporary Science, Technology, and Medicine* (London and New York: Routledge, 2006).

⁵ I have learned a great deal about history of computing from my CBI colleagues Arthur Norberg and Jeffrey Yost. My working bibliography can be found at

<www.umn.edu/~tmisa/biblios/hist_computing.html>. Perceptive reviews of computer historiography, in addition to the essays by Michael Mahoney, Paul Edwards, and Martin Campbell-Kelly cited below, include William Aspray, "The History of Computing within the History of Information Technology," *History and Technology* 11 (1994): 7-19; Paul N. Edwards, "From 'Impact' to Social Process: Computers in Society and Culture," in Sheila Jasanoff, Trevor Pinch, Gerald Markle, and James Petersen, eds., *Handbook of Science and Technology Studies* (Beverly Hills: SAGE Publications, 1994), chapter 12; Edwards, "Virtual Machines, Virtual Infrastructures: The New Historiography of Information Technology," *Isis* 89 no. 1 (1998): 93-99; Ulf Hashagen, Reinhard Keil-Slawik, and Arthur L. Norberg, eds., *History of Computing: Software Issues* (Berlin/New York: Springer, 2002); Jeffrey R. Yost, "Computers and the Internet: Braiding Irony, Paradox, and Possibility," in Carroll Pursell, ed., *Companion to American Technology* (Oxford: Blackwell, 2005), pp. 340-360. An important website full of useful information and links is Tom Haigh's "History Resources" at <www.tomandmaria.com/tom/Resources/ResourceFile.htm>. For another view of the field, Martin Campbell-Kelly has compiled a range of courses in the history of computing; see <www.dcs.warwick.ac.uk/~mck/HoC_Courses.html> (Sept. 2006).

⁶ Slowly the long-standing Anglo-American bias in history of computing is being corrected. Work by European historians of computing has both broadened and deepened in the last decade or so. One institutional manifestation is the computing history research group within the "Tensions of Europe" project; see <www.histech.nl/tensions/Projecten/IT/ITMain.htm> and the discussion about Europe in this article. See also the Indiana University conference "Informatics Goes Global: Methods at a Crossroads," at <rkcsi.indiana.edu/article.php/conferences2/45> (Sept. 2006); the History of

Nordic Computing conferences (June 2003 Trondheim, Norway; August 2007 Turku, Finland); the IFIP Working Group 9.7 on History of Computing <www.comphist.org> (Feb. 2007); and the active research and exhibition programs at the Deutsches Museum (Munich) and Heinz Nixdorf MuseumsForum (Paderborn). Research on topics in Asia is also emerging in the work of Chigusa Kita, Richard Heeks (*India's Software Industry: State Policy, Liberalisation and Industrial Development* [Sage, 1996]), and Ross Bassett on the Indian Institutes of Technology; in addition many economists and business scholars have written about the rise of the Asian IT industries. Such a geographical-cultural bias is of course hardly unique to computing history; for contemporary science studies see Alexis De Greiff A. [sic] and Mauricio Nieto Olarte, "What We Still Do Not Know about South–North Technoscientific Exchange," in Ronald E. Doel and Thomas Söderqvist, eds., *The Historiography of Contemporary Science, Technology, and Medicine* (London and New York: Routledge, 2006), pp. 239-259.

⁷ David Nye, *Technology Matters: Questions to Live With* (Cambridge: MIT Press, 2006), pp. 194-98.

⁸ See Jennifer S. Light, "When Computers Were Women," *Technology and Culture* 40 no. 3 (1999): 455-483; David Alan Grier, *When Computers Were Human* (Princeton: Princeton University Press, 2005).

⁹ Emerson W. Pugh, *Memories that Shaped an Industry: Decisions Leading to IBM System/360* (Cambridge: MIT Press, 1984); Pugh, *Building IBM: Shaping an Industry and its Technology* (Cambridge: MIT Press, 1995); and Pugh, Lyle R. Johnson, and John H. Palmer, *IBM's 360 and early 370 Systems* (Cambridge: MIT Press, 1991).

¹⁰ Arthur W. Burks, *The First Electronic Computer: The Atanasoff Story* (Ann Arbor: University of Michigan Press, 1988); Alice Rowe Burks, *Who Invented the Computer? The Legal Battle That Changed Computing History* (Prometheus Books, 2003).

¹¹ Michael S. Mahoney, "The History of Computing in the History of Technology," *Annals of the History of Computing* 10 no. 2 (1988): 113-125.

¹² James S. Small, "General-purpose Electronic Analog Computing: 1945-1965," *Annals of the History of Computing* 15 no. 2 (1993): 8-18; Small, *The Analogue Alternative: The Electronic Analogue Computer in Britain and the USA, 1930-1975* (New York/London: Routledge, 2001); David Mindell, *Between Human and Machine: Feedback, Control, and Computing Before Cybernetics* (Baltimore: Johns Hopkins, 2002). See additional citations at <www.umn.edu/~tmisa/biblios/hist_computing.html#Analog-Era>

¹³ Larry Owens, "Vannevar Bush and the Differential Analyzer: The Text and Context of an Early Computer," *Technology and Culture* 27 (1986): 63-95; Larry Owens, "Where are we going Phil Morse? Changing Agendas and the Rhetoric of Obviousness in the Transformation of Computing at MIT, 1939-1957," *Annals of the History of Computing* 18 no. 4 (1996): 34-41; Aristotle Tympas, "From Digital to Analog and Back: The Ideology of Intelligent Machines in the History of the Electrical Analyzer, 1870s-1960s," *Annals of the History of Computing* 18 no. 4 (1996): 42-48.

¹⁴ Tracy Kidder, *The Soul of a New Machine* (Boston: Little, Brown, 1981), pp. 29-32; Donald MacKenzie, *Knowing Machines: Essays on Technical Change* (Cambridge: MIT Press, 1996).

¹⁵ Lawrence Lessig, *Code and Other Laws of Cyberspace* (New York: Basic Books, 1999); Jay P. Kesan and Rajiv C. Shah, "Fool Us Once Shame On You - Fool Us Twice

Shame On Us: What We Can Learn From the Privatizations of the Internet Backbone Network and the Domain Name System,” *Washington University Law Quarterly* 79 (2001): 89-220; Jay P. Kesan and Rajiv C. Shah, “Deconstructing Code,” *Yale Journal of Law & Technology* 6 (2003-2004): 277-389; Jay P. Kesan and Rajiv C. Shah, “Shaping Code,” *Harvard Journal of Law & Technology* 18, no. 2 (Spring 2005): 319-399.

¹⁶ The essay is at www.iee.org/OnComms/pn/History/HistoryWk_History_of_Computing.pdf (2 March 2006).

¹⁷ Martin Campbell-Kelly and William Aspray, *Computer: A History of the Information Machine* (New York: Basic Books, 1996); Alfred D. Chandler, Jr., and James W. Cortada, eds., *A Nation Transformed by Information: How Information Has Shaped the United States from Colonial Times to the Present* (Oxford University Press, 2000); Paul E. Ceruzzi, *A History of Modern Computing* (Cambridge: MIT Press, 1998; second edition 2003); Michael Riordan and Lillian Hoddeson, *Crystal Fire: The Birth of the Information Age* (New York: Norton, 1997).

¹⁸ James W. Cortada, *Before the Computer: IBM, NCR, Burroughs, and Remington Rand and the Industry They Created, 1865-1956* (Princeton: Princeton University Press 1993), p. 109.

¹⁹ Jon Agar, *The Government Machine: A Revolutionary History of the Computer* (Cambridge: MIT Press, 2003); Martin Campbell-Kelly, *From Airline Reservations to Sonic the Hedgehog: A History of the Software Industry* (Cambridge: MIT Press, 2003); JoAnne Yates, *Structuring the Information Age: Life Insurance and Technology in the Twentieth Century* (Baltimore: Johns Hopkins University Press, 2005).

²⁰ Arthur L. Norberg and Judy E. O'Neill. *Transforming Computer Technology: Information Processing for the Pentagon, 1962-1986* (Baltimore: Johns Hopkins University Press, 1996); Donald MacKenzie, "The Influence of the Los Alamos and Livermore National Labs on Supercomputing," *Annals of the History of Computing* 13 no. 2 (1991): 179-201; Janet Abbate, *Inventing the Internet* (Cambridge: MIT Press, 1999); Alex Roland and Philip Shiman, *Strategic Computing: DARPA and the Quest for Machine Intelligence, 1983-1993* (Cambridge: MIT Press, 2002). In addition to Steven W. Usselman, "IBM and Its Imitators: Organizational Capabilities and the Emergence of the International Computer Industry," *Business and Economic History* 22 no. 2 (Winter 1993): 1-35, see his forthcoming essays, "Unbundling IBM: Antitrust and the Incentives to Innovation in American Computing" and "Learning the Hard Way: IBM and the Sources of Innovation in Early Computing."

²¹ Kenneth Flamm, *Creating the Computer: Government, Industry and High Technology* (Washington: Brookings Institution, 1988); National Research Council, *Funding a Revolution: Government Support for Computing Research* (Washington, D.C.: National Academy Press, 1999) available at <www.nap.edu/readingroom/books/far/contents.html>.

²² See Thomas J. Misa, "Revisiting the 'Rate' and 'Direction' of Technical Change: Scenarios and Counterfactuals in the Information Technology Revolution," paper to the Society for the History of Technology (Las Vegas) 14 Oct. 2006.

²³ Paul Edwards, "Making History: New Directions in Computer Historiography," *Annals of the History of Computing* (Jan.-Mar. 2001): 86-87. For an exploration, see Aristotle Tympas, "From Digital to Analog and Back: The Ideology of Intelligent Machines in the History of the Electrical Analyzer, 1870s-1960s," *Annals of the History of Computing* 18 no. 4 (Winter 1996): 42-48.

²⁴ See the articles of Larry Owens cited above; as well as Paul N. Edwards, *The Closed World: Computers and the Politics of Discourse in Cold War America* (Cambridge: MIT Press, 1996).

²⁵ Recently business and technological historians have strengthened their common concerns, with such figures as JoAnne Yates, David Kirsch, Steve Usselman, and others playing prominent roles. See the symposium discussion built around Yates, “How Business Enterprises Use Technology: Extending the Demand Side Turn,” *Enterprise and Society* 7 no. 3 (2006): 422-455. Calls to investigate the “demand side” of computing stretch back at least to Aspray op. cit. (1994), p. 14.

²⁶ Jennifer S. Light, “When Computers Were Women,” *Technology and Culture* 40 no. 3 (1999): 455-483; William Aspray and Nathan Ensmenger, “Software as Labor Process,” in Hashagen et al. op cit.; Michael S. Mahoney, “Boys’ Toys and Women’s Work: Feminism Engages Software,” in Angela N.H. Creager, Elizabeth Lunbeck, and Londa Schiebinger, eds., *Feminism in Twentieth-Century Science, Technology, and Medicine* (Chicago: University of Chicago Press, 2001), 169-185; Janet Abbate, “Women and Gender in the History of Computing,” *Annals of the History of Computing* 25 (October-December 2003): 4-8; Charlie Yood, “The History of Computing at the Consumption Junction,” *Annals of the History of Computing* 27 no. 1 (2005): 86-88. There is a wider literature on the underrepresentation of women in computing; see Jane Margolis and Allan Fisher, *Unlocking the Clubhouse: Women in Computing* (Cambridge, MA: MIT Press, 2002); J. McGrath Cohoon and William Aspray, eds., *Women and Information Technology: Research on Underrepresentation* (Cambridge: MIT Press, 2006).

²⁷ See the work by Yates and Usselman cited above; and Jan Fagerberg, David C. Mowery, and Richard R. Nelson, eds. *The Oxford Handbook of Innovation* (Oxford University Press, 2006).

²⁸ Michael S. Mahoney, "Software as Science—Science as Software," in Ulf Hashagen, Reinhard Keil-Slawik, and Arthur Norberg, eds., *History of Computing: Software Issues* (Berlin/New York: Springer Verlag, 2002), pp. 25-48; Atsushi Akera and William Aspray, eds., *Using History to Teach Computer Science and Related Disciplines* (Washington, DC: Computing Research Association, 2004); Michael S. Mahoney, "Finding a History for Software Engineering," *IEEE Annals of the History of Computing* 26 no. 1 (Jan.-March 2004): 8-19; Atsushi Akera, *Calculating a Natural World: Scientists, Engineers, and Computers during the Rise of U.S. Cold War Research* (Cambridge: MIT Press, 2007).

²⁹ In 2005 the National Science Foundation established an Office of Cyberinfrastructure to deal proactively with designing, building and using computer networks across the research enterprise; see <www.nsf.gov/dir/index.jsp?org=OCI> (24 Sept. 2006).

³⁰ For analysis and cases attempting this twin-fold analysis, see Thomas Misa, Philip Brey, and Andrew Feenberg, eds., *Modernity and Technology* (Cambridge: MIT Press, 2003); Misa, *Leonardo to the Internet: Technology and Culture from the Renaissance to the Present* (Baltimore: Johns Hopkins University, 2004).

³¹ Alfred D. Chandler, Jr. and James W. Cortada, *A Nation Transformed by Information: How Information Has Shaped the United States from Colonial Times to the Present* (New York: Oxford University Press, 2000); Daniel R. Headrick, *When Information Came of Age: Technologies of Knowledge in the Age of Reason and Revolution, 1700-1850* (New York: Oxford University Press, 2002).

³² Thanks to Alex Pang of the Institute for the Future (Palo Alto) for this formulation.

³³ This attention to distinct lines of research as well as different companies that experienced both leadership as well as problems certainly distinguishes Arthur L. Norberg, *Computers and Commerce: A Study of Technology and Management at Eckert-Mauchly Computer Company, Engineering Research Associates, and Remington Rand, 1946-1957* (Cambridge: MIT Press 2005).

³⁴ Early computing in the former Soviet Union is investigated in G.D. Crowe and S.E. Goodman, "S.A. Lebedev and the birth of Soviet computing," *Annals of the History of Computing* 16 no. 1 (1994): 4-24; Anne Fitzpatrick, Tatiana Kazakova, and Simon Berkovich, "MESM and the Beginning of the Computer Era in the Soviet Union," *Annals of the History of Computing* 28 no. 3 (2006): 4-17; Hiroshi Ichikawa, "Strela-1, the First Soviet Computer: Political Success and Technological Failure," *Annals of the History of Computing* 28 no. 3 (2006): 18-31; and Slava Gerovitch, *From Newspeak to Cyberspeak: A History of Soviet Cybernetics* (Cambridge: MIT Press, 2002). For years Soviet computing depended on the reverse engineering of IBM machines, see N. C. Davis and S. E. Goodman, "The Soviet Bloc's Unified System of Computers," *ACM Computing Surveys* 10 no. 2 (June 1978): 93-122.

³⁵ See the works cited by Edwards, MacKenzie, and Norberg and O'Neill cited above. Other valuable studies of computing in the Cold War context include Agatha C. Hughes and Thomas P. Hughes, eds., *Systems, Experts, and Computers: The Systems Approach in Management and Engineering, World War II and After* (Cambridge: MIT Press, 2000); Slava Gerovitch, *From Newspeak to Cyberspeak: A History of Soviet Cybernetics* (Cambridge: MIT

Press, 2002); Atsushi Akera, *Calculating a Natural World: Scientists, Engineers, and Computers During the Rise of U.S. Cold War Research* (Cambridge: MIT Press, 2006).

³⁶ AnnaLee Saxenian, *Regional Advantage: Culture and Competition in Silicon Valley and Route 128* (Cambridge: Harvard University Press, 1994).

³⁷ Stuart W. Leslie, *The Cold War and American Science: The Military-Industrial-Academic Complex at MIT and Stanford* (New York: Columbia University Press, 1993); Rebecca S. Lowen, *Creating the Cold War University: The Transformation of Stanford* (Berkeley: University of California Press, 1997); Ross Knox Bassett, *To the Digital Age: Research Labs, Start-Up Companies, and the Rise of MOS Technology* (Baltimore: Johns Hopkins University Press, 2002); Leslie Berlin, *The Man Behind the Microchip: Robert Noyce and the Invention of Silicon Valley* (New York: Oxford University Press, 2005); Christophe Lécuyer, *Making Silicon Valley: Innovation and the Growth of High Tech, 1930-1970* (Cambridge: MIT Press, 2005).

³⁸ Vernon Ruttan, *Is War Necessary for Economic Growth?* (Oxford University Press, 2006).

³⁹ James Cortada, *The Digital Hand* (New York: Oxford, 2004-2008, three volumes); Yates, "How Business Enterprises Use Technology" cited above; Eric von Hippel, *Democratizing Innovation* (Cambridge: MIT Press, 2005); Nelly Oudshoorn and Trevor Pinch, eds., *How Users Matter: The Co-Construction of Users and Technology* (Cambridge: MIT Press, 2005).

⁴⁰ For examples of popular culture studies, see Cheryl Malone, "Imagining Information Retrieval in the Library: *Desk Set* in Historical Context," *Annals of the History of Computing* (July-Sept. 2002): 14-22; Edwards, *Closed World*; Ted Friedman, *Electric*

Dreams: Computers in American Culture (New York: New York University Press, 2005); John Markoff, *What the Dormouse Said: How the Sixties Counterculture Shaped the Personal Computer Industry* (New York: Viking Penguin, 2005); Fred Turner, *From Counterculture to Cyberculture: Stewart Brand, the Whole Earth Network, and the Rise of Digital Utopianism* (University Of Chicago Press, 2006). For relevant scholarship in rhetoric, see Stephen Doheny-Farina, *Rhetoric, Innovation, Technology: Case Studies of Technical Communication in Technology Transfers* (Cambridge MIT Press, 1992); Laura J. Gurak, *Persuasion and Privacy in Cyberspace* (New Haven: Yale University Press, 1997); Barbara Warnick, *Critical Literacy in a Digital Era: Technology, Rhetoric, and the Public Interest* (Mahwah, NJ: Lawrence Erlbaum Associates, 2002); Rosemary Coombe and Andrew Herman, "Rhetorical Virtues: Property, Speech, and the Commons on the World-Wide Web," *Anthropological Quarterly* 77 no. 3 (Summer 2004): 559-574; John Logie, *Peers, Pirates, and Persuasion: Rhetoric in the Peer-to-Peer Debates* (West Lafayette, IN: Parlor Press, 2006).

⁴¹ See Thomas J. Misa and Johan Schot, "Inventing Europe: Technology and the Hidden Integration of Europe," *History and Technology* 21 no. 1 (2005): 1-19; Erik van der Vleuten and Arne Kaijser, eds., *Networking Europe: Transnational Infrastructures and the Shaping of Europe, 1850-2000* (Sagamore Beach, MA: Science History Publications, 2006); and Mikael Hard and Thomas J. Misa, eds., *Urban Machinery: Inside Modern European Cities* (Cambridge: MIT Press, 2008).

⁴² See the European Science Foundation's EUROCORES announcement at <www.esf.org/inventingeurope> and the new project's website at <www.histech.nl/inventing/index.htm>.

⁴³ In addition to the essays by Mollick and Ceruzzi, cited above, see David Brock, ed., *Understanding Moore's Law: Four Decades of Innovation* (Chemical Heritage Press, 2006).

⁴⁴ S.E. Goodman, "The Globalization of Computing: Perspectives on a Changing World," *Communications of ACM* 34 no. 1 (January 1991): 19-21 (quote p. 19).

⁴⁵ See the Basel Action Network's *The Digital Dump: Exporting Re-Use and Abuse to Africa* (October 24, 2005) <www.ban.org/Library/TheDigitalDump.pdf>.

⁴⁶ William Aspray, Frank Mayadas, and Moshe Y. Vardi, eds. *Globalization and Offshoring of Software: A Report of the ACM Job Migration Task Force* (Association for Computing Machinery, 2006).

⁴⁷ James Cortada, "How did Computing go Global? The Need for an Answer and a Research Agenda," *IEEE Annals of the History of Computing* 26 no. 1 (Jan.-March 2004): 53-58. For suggestive leads, perspectives, and case studies, see also W.M. Carlson, "Transforming an Industry Through Information Technology," *IEEE Annals of the History of Computing* 15 no. 1 (1993): 39-43; Jan van den Ende, "Computers and Industrial Organization: Early Sources of 'just in time' Production in the Dutch Steel Industry," *IEEE Annals of the History of Computing* 17 no. 2 (Summer 1995): 22-32; Jan Mazurek, *Making Microchips: Policy, Globalization, and Economic Restructuring in the Semiconductor Industry* (Cambridge: MIT Press, 1999); Paula Gabbert, "Globalization and the Computing Curriculum," *ACM SIGCSE Bulletin* 35 no. 2 (June 2003): 61-65; Corinna Schlombs, "Toward International Computing History," *IEEE Annals of the History of Computing* 28 no. 1 (Jan.-March 2006): 108; Paul N. Edwards "Meteorology as Infrastructural Globalism," *Osiris* 21 (2006): 229-250; Andy Ju An Wang, "IT Education in the Flattening World,"

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