The History of Information Technology

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In many scholarly fields the new entrant must work carefully to discover a gap in the existing literature. When writing a doctoral dissertation on the novels of Nabokov or the plays of Sophocles, clearing intellectual space for new construction can be as difficult as finding space to erect a new building in central London. A search ensues for an untapped archive, an unrecognized nuance, or a theoretical framework able to demolish a sufficiently large body of existing work.

The history of information technology is not such a field. From the viewpoint of historians it is more like Chicago in the mid-nineteenth century (Cronon, 1991). Building space is plentiful. Natural resources are plentiful. Capital, infrastructure, and manpower are not. Boosters argue for its "natural advantages" and promise that one day a mighty settlement will rise there. Speculative development is proceeding rapidly and unevenly. But right now the settlers seem a little eccentric and the humble structures they have erected lack the scale and elegance of those in better developed regions. Development is uneven and streets fail to connect. The native inhabitants have their ideas about how things should be done, which sometimes causes friction with new arrivals. In a generation everything will be quite unrecognizable, but how?

This is a guide to the growing (if ramshackle) secondary literature in the history of information technology: monographs, edited volumes, and journal articles written to explore different aspects of computing from historical perspectives. Except as a frame in which to situate these secondary works, and reveal gaps in their coverage, I cannot attempt here to recount the substance of that history. My discussion here is biased toward books rather than articles. Books are the primary unit of scholarly production for historians, and few significant topics can be dealt with fully within the confines of a journal article. Material initially presented in article form often receives its mature presentation in monographs. However articles and unpublished dissertations are referenced when they provide material unavailable elsewhere.

Information Technology vs. Computing

In this chapter I consider digital computer technologies and their applications but neglect communication technologies (other than those used for computer communication) and all analog or nonelectronic information technologies. This distinction reflects current segmentation in the world of historical specialists. The history of communications technology is still written and read primarily by a different community from the history of computer technology and has evolved its own questions (Aspray, 1994). The history of information science (Hahn & Buckland, 1998) has been written almost entirely within the information science discipline. Likewise library history (Wigland & Davis, 1994), media history, and history of the book are all well developed fields written in different academic niches and progressing in almost complete isolation from the history of computer technology.

Fortunately the difficulties and rewards of "information history" as a category to bridge some of these divides have already been considered expertly in a recent ARIST chapter (Black, 2006), as has the rapidly developing literature on the history of information science (Burke, 2007). These helpfully constrain my brief to the history of information technology. But even this is a problematic and potentially sprawling category. Treating information technology and computing as interchangeable concepts generally makes me a little uneasy, so let me explain my decision to do so here. Looking at its two constituent words would suggest that "information technology" should include everything from ancient clay tablets through scrolls and books to communication systems of all kinds, newspapers, street signs, libraries, encyclopedias, and any artifact used for educational purposes. And indeed one sometimes sees such expansive definitions in textbooks of library and information science. I pass no judgment on the inherent merit of such a definition in observing that outside this rather small community the phrase is almost never used in this way.

In fact the great majority of references to "information technology" have always been concerned with computers, though the exact meaning has shifted over time (Kline, 2006). The phrase received its first prominent usage in a *Harvard Business Review* article (Haigh, 2001b; Leavitt & Whisler, 1958) to promote a technocratic vision for the future of business management. Its initial definition was as the conjunction of computers, operations research methods, and simulation techniques. Having failed initially to gain much traction (unlike related terms of a similar vintage such as information systems, information processing, and information science) it was revived in policy and economic circles in the 1970s with a new meaning. Information Technology now described the expected convergence of the computing, media, and telecommunications industries (and their technologies), understood within the broader context of a wave of enthusiasm for the computer revolution, post-industrial society, information society (Webster, 1995), and other fashionable expressions of the belief that new electronic technologies were brining a profound rupture with the past. As it spread broadly during the 1980s, IT increasingly lost its association with communications (and, alas, any vestigial connection to the idea of anybody actually being informed of anything) to become a new and more pretentious way of saying “computer.” The final step in this process is the recent surge in references to “information and communication technologies” or ICTs, a coinage which makes sense only if one assumes that a technology can inform without communicating.

In the history of information technology, as in other areas defined through reference to “information,” definitions are problematic and categories unstable. As Lionel Fairthorne observed more than forty years ago (Fairthorne, 1965, p. 10), the word’s appeal is often as “a linguistic convenience that saves you the trouble of thinking about what you are talking about.” Valiant attempts have been made to create definitions of information (Capurro & Hjorland, 2003) broad enough to bolster the territorial ambitions of information science and coherent enough to be useful, but as an historian I am impressed more by the enduring lack of consensus around its actual meaning. Information, like other concepts such as progress, freedom, or democracy has become ubiquitous because of, not despite, its impressive degree of interpretative flexibility. Information has been seized upon by many different social groups, each of which has produced hybridized notions such as “information science,” “information worker” and “information system.” Definitions of these terms attempt to demarcate boundaries (Gieryn, 1983) for the authority of particular specialist groups, and so are frequently contested and have evolved haphazardly over time. Such phrases are rarely taken to mean what one would expect by looking up their constituent words in a dictionary.

This is a particular problem for the historian, since one is wary to frame one’s work using analytical categories that embed the interests and assumptions of one or another group of the actors one is writing about. It is hard even to find a vocabulary to describe long term continuities of practice across these rhetorical ruptures. For example, I have sometimes described my own ongoing research project "a history of information processing and its management in American business over the twentieth century," yet only in the 1960s would the idea that routine administrative systems involved "processing information" have begun to seem plausible to my historical actors. The emergence of information as a crucial building block of occupational identities and system building discourse is an important part of what set the corporate computer staff of the 1960s apart from office managers of the 1920s. Yet the very act of framing my story as one about information and its manipulation tends to obscure this crucial rhetorical innovation.

My other source of ambivalence toward the title of this chapter is that "history of computing," rather than "history of information technology" has traditionally been the phrase more widely adopted by specialists in the field. This is probably a result of the naming of the field's primary journal *Annals of the History of Computing* back in the 1970s, which in turn reflected its sponsorship by AFIPS, a now defunct professional umbrella group that had adopted "computing" as an identity bridging the interests of its constituent societies in mathematical calculation, computer science, business data processing, and so on. Computing, however, has come to sound a little vulgar and old fashioned next to information technology, and so a number of name changes have taken place in recent years. The Charles Babbage Foundation recently became the IT History Society, and the Charles Babbage Institute, the field's leading research center, now bills itself as a "Center for the History of Information Technology." So it seems inevitable that the history of computing is eventually going to complete its rebranding as the history of information technology.[1] This may in time facilitate more interaction between specialists in the history of computing and those working on other aspects of information history.

[1] This transition is not entirely unproblematic. "Computing" has its own conceptual limitations as it literally refers to the act of calculation. This was the original task of computers but has become something of a misnomer given the rapid development of their capabilities and applications. But it retains two advantages over information technology. It is more descriptive of the kinds of technology that are actually being considered. And it describes an activity, albeit one performed with technology, rather than the technology itself. "History of

Origins of the History of Information Technology

The computer's history has been told for as long as there have been computers. Historian Michael S. Mahoney observed, in this context, that "nothing is really unprecedented. Faced with a new situation, people liken it to familiar ones and shape their responses on the basis of the perceived similarities." (Mahoney, 1990) The search for precedent is also a search for a narrative. Humans make sense of the world by telling stories to themselves and each other (Weick, 1995), and so to understand and explain the first electronic computers it was necessary to package them inside a story.

One sees this most strikingly in Edmund Callis Berkeley's classic 1949 book *Giant Brains, or Machines that Think* (Berkeley, 1949). This was the first popular treatment of the new technology, providing an introduction to the hitherto obscure world of computing to a generation of impressionable youngsters. He described computers of the 1940s, such as the ENIAC, MIT's differential analyzer, and the series of machines built by Harvard and Bell Labs in some detail. Berkeley made an unconventional choice in building his story. The most obvious understanding of the early computer was a calculating machine, literally as something performing computations. For decades to come these inventions were usually understood, for example in (Goldstein, 1972) and (M. R. Williams, 1985), as a natural evolution of earlier calculating devices such as the hand cranked calculators widely used in business.

Berkeley, however, downplayed this understanding of the computer. Berkeley called the computer a giant brain not because it could think but because it "can handle information with great skill and great speed." (p. vii) This sense-making narrative was much more novel at the time, though it has since become a cliché. In this context the digital computer was precedented by earlier machines and systems for handling information, such as nerve cells, cave paintings, beads on strings, and human language (p. 10-13). But, in "a deep break from the past" it could transfer "information from one part of the machine to another [with] flexible control over the sequence of its operation." (p. 5) In other words, it could execute a program. This framing led Berkeley to an exceptionally bold set of predictions as to the

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Information Technology," like "History of the Computer" puts the emphasis on the obsolete widgets and doodads themselves rather than their associated applications, work practices, cultural meanings, and influence on the world.

future impact of computer technology, which he predicted “will take a load off man's minds as great as the load that printing took off men's writing” (vii) thanks to the perfection of capabilities such as automatic transcription and translation, machine vision, economic simulation, weather prediction, and even computerized psychotherapy. After making a preemptive strike on anti-computer prejudice as a disease in need of treatment he concluded that we should get ready to “welcome the robot machine as our deliverer from the long hard chores of many centuries." (p. 208)

One particular strand of computing history was heavily researched and exhaustively argued during the early 1970s. The inventors of the ENIAC eventually received a patent and its holder was seeking hundreds of millions of dollars in licensing fees from the other major computer companies. Several years of legal action centered on the circumstances and timing of their work and its relationship to prior art, documented in a trial transcript of more than twenty thousand pages. No other historical topic has ever assumed a similar practical urgency for the computer industry. Academic historians are not particularly concerned with assigning firsts but this question has continued to resonate elsewhere (A. R. Bucks, 2003). Even today, if one looks up the reviews on Amazon.com for a general history of computing many of the reviews will invariably focus on whether or not the author answers this question “correctly.” Partisans for the German contender Konrad Zuse or Iowa’s oft-forgotten John Atanasoff are quick to lash out with one star reviews at those who slight the contributions of their idols. Historians try to sidestep such problems by employing long strings of hyphenated adjectives, so that a particular machine might hypothetically be described not as “the first computer” but as “the first large-scale general-purpose stored-program digital electronic computer to enter regular operation.”

The history of computing emerged as an area of scholarly research during the 1970s. The pioneering generation of computer industry leaders and academic computer specialists started to develop an interest in preserving the history of their cohort’s accomplishments in the face of milestone anniversaries, encroaching mortality, and a sense that the heritage of their communities was at risk. In the late 1960s and early 1970s this was reflected in a set of conference sessions organized by the Association for Computing Machinery (ACM) and a major investment (Carlson, 1986) made by the Association of

Information Processing Societies (AFIPS) to support a Smithsonian program of oral histories (Tropp, 1980) with pioneers from the earliest days of electronic computing. The late 1970s saw the launch of two ventures that have provided the field's institutional backbone for three decades now: the journal *Annals of the History of Computing* (Galler, 2004) and the Charles Babbage Institute (Aspray, 2007; Arthur L Norberg, 2001). Chartered by the newly created Charles Babbage Foundation and supported financially by AFIPS the latter found a previous home at the University of Minnesota, along with an endowed chair and the Tomash dissertation fellowship. Several computer museums were established with local support, most notably the Computer Museum in Boston.

Computer scientists and other pioneers were, during this period, the main suppliers and consumers of historical work. Bernie Galler (Akera, 2008), the founding editor of Annals of the History of Computing was famous for his work on timesharing operating systems. Paul Armer, formerly head of numerical analysis at the RAND Corporation, headed the Charles Babbage Foundation. The most important early edited volume on the history of computing (Metropolis, Howlett, & Rota, 1980) was prepared by members of the Los Alamos scientific computing staff. The first textbook for the computer history *The Computer from Pascal to von Neumann* (Goldstein, 1972) was a mixture by of historical research and memoir from a close collaborator of von Neumann.

The past three decades have seen a steady shift of activity away from retired participants and toward younger scholars with graduate training in history or science studies. This appears to be a common pattern in the historical study of scientific, technical and professional fields. While a few senior historians, such as I Bernard Cohen of Harvard University, developed new interests in the field most new entrants were graduate students. Indeed the list of winners of the Tomash dissertation fellowship (Yost, 2001) offered by the Charles Babbage Institute also serves as a register for most of those who have gone on to do important work in the area. Today the editorial board of IEEE Annals of the History of Computing is dominated by Ph.D. historians, including (for the first time) the editor in chief. Research practices in the field usually follow the humanities model: individual researchers, lots of archival work, rare and tiny grants, and primary publication in monographs. Some grants of appreciable size have been received to support historical projects run by professional societies or experiments with use of web communities to capture historical memory.

This shift has been associated with a gradual evolution in the kinds of research being done. Much historical writing done by computer specialists has been far more than simple memoir, and many works by pioneers involved significant research in journals and archives to give balance to their accounts, solve mysteries, and verify facts. But historical work carried out by members of a field inevitably has a different character from work performed by outsiders. Scholars have long distinguished between "internalism" and "externalism" as approaches toward the history of scientific and technical fields.[2] The primary difference concerns the ways in which historical work is framed and the implicit research questions guiding the historian. Internalist work is typically written within the conceptual framework of the specialist community involved. It focuses on important discoveries or inventions, fitting specific episodes into a trajectory of development and (almost invariably) progress. Its insights are directed at an assumed readership within the discipline. Externalist work is explicitly concerned with integrating developments within a particular specialized field with broader historical trajectories, such as major political, social, or economic shifts (for example the Cold War or Industrial Revolution). This involves reinterpreting the history of a community according to a set of perspectives and concerns that might be very different from those held by the historical actors themselves. The work of trained historians, particularly those without advanced training in information technology, will naturally be oriented toward questions of interest to other historians and so is more often associated with the externalist approach. Of course one can write good and bad history from either perspective.

Not all changes since the 1970s have been positive. Changes in the computer industry have eliminated many of the early sources of support for historical work. Today's leading computer companies

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[2] In actuality scholars have tended to back away from the idea that this is a simple dichotomy and seek more nuanced or hybrid approaches. One problem is that "internal" and "external" are often expressed not just with reference to a specific identifiable community but with reference to science as a whole, and modern work in science studies challenges the whole idea of science as something with a definable inside or outside. However the idea of a split in approaches is still a useful one in this context.

have short term cultures, downplay corporate philanthropy, keep few accessible archives and sponsor almost no historical projects. AFIPS collapsed, though publication of Annals of the History of Computing was taken up by the IEEE Computer Society which has provided a stable home since 1992. Interest in historical projects still waxes and wanes among the professional societies, but with a preponderance of waning. However in recent years the Association for Computing Machinery has supported an ACM History Committee. Its main achievement to date is arranging for the archiving of the society's records. The Computer Museum folded as DEC ran into trouble, though much of its collection made its way to California where it formed the core holdings of a new Computer History Museum in the heart of Silicon Valley. So far the museum has built excellent connections with computer industry executives and technology enthusiasts but has had few interactions with historians.

In contrast, interest in information technology within scholarly associations such as the Business History Conference, the Society for the Social Studies of Science, the History of Science Society and (especially) the Society for the History of Technology has been rising consistently albeit from a very low base. The latter includes a thriving specialist group, the Special Interest Group on Computers, Information and Society (SIGCIS). The field is also becoming far more international, with major projects underway in many European countries. It is increasingly interdisciplinary. Scholars usually approach topics in the history of information technology from within the perspectives of historical sub disciplines (business, labor, social, technology, economic, or science) and frame their contributions within these literatures rather than primarily as a contribution to the history of information technology. This brings diversity, though it does slow the development of a canon, common research agenda, or a shared core set of concerns.

The institutional affiliation of scholars in the field is similarly diverse. Few history departments or science studies programs have actively sought to hire in the history of IT, but many scholars trained in this area have found academic employment in schools of information, business, communication or (outside the US) computer science. This presents opportunities for interdisciplinary collaboration and outreach to professional communities, but also threatens them with institutional marginality and reduces opportunities to teach or supervise new generations of specialists in the history of information technology.

Bibliographic Guides and Reviews

One can chart the developments discussed above by looking at the images of the field presented in introductory articles, review articles, and manifestos over the years. The earliest articles such as (May, 1980) were aimed at giving computer scientists a general idea of historical methods and concerns. The same task has been attempted frequently over the years, recently in (Haigh, 2004a). Two major articles of the 1980s (Aspray, 1984; Mahoney, 1988) captured the field as credentialed historians were first beginning to make their mark. Aspray sketched its institutional development and categorizes major early works, while Mahoney glided rapidly over existing work in the field ("historians stand before the daunting complexity of a subject that has grown exponentially in size and variety, looking not so much like an uncharted ocean as like a trackless jungle. We pace on the edge, pondering where to cut in…" p. 115) to discuss research questions from better developed areas of the history of technology that might profitably be applied to computing. Both bemoaned the many gaps in topics and approaches. Reviews (Aspray, 1994; Mahoney, 1996) from the same authors published in the 1990s followed a similar pattern. Aspray acknowledged gaps (particularly the study of applications and software) but also noted rapid growth in the field, new activity internationally, and a number of promising studies underway. Mahoney again stressed conceptual poverty: "we have lots of answers but very few questions, lots of stories but no history, lots of things to do but no sense of how to do them or in what order. Simply put, we don't yet know what the history of computing is really about." (p. 772) Shortly after becoming director of the Charles Babbage Institute, Tom Misa (Misa, 2007) surveyed the literature from the viewpoint of a historian of technology, noting a reluctance to engage with the part computer technology has actually played in reshaping society. The regular "Think Piece" opinion column in *IEEE Annals of the History of Computing* can be counted on to feature a historian proposing calling on the community to adopt one or another perspective from more mature historical communities (comparative history, social history, memory studies, etc.).

Much has changed over thirty years, but the message that our challenges are great, our concerns parochial, and our methods mostly inadequate has been a constant. Following this tradition, I have found myself composing many variations on the same sentence (indeed so many that I edited most out). This sentence informs the reader that the existing literature on a particular aspect of the history of information technology is, at best, full of holes and that most of the obvious topics have been utterly neglected. It is generally followed with the sad caution that even those episodes which have been explored have usually been examined from a rather narrow perspective that ignores issues of general importance to historians.

James Cortada has been the field's most prolific assembler of annotated bibliographies, addressing the history of computing, with particular reference to business history, in (Cortada, 1996a, 1996b). He has also cataloged sources on the history of computer applications (Cortada, 1996a). Another survey examines sources for scientific computing (Yost, 2002). Such guides are perhaps less widely used within the history of information technology than in other fields because the vast array of accessible sources for recent decades means that no guide can aim to cover all, or even a significant fraction, of them. Archival resources are surveyed in (Cortada, 1990) and (Bruemmer, 1987). Both are conspicuously dated, but still useful for locating personal papers or collections held at institutions one would not otherwise think to examine. Books about the history of computing are surveyed with useful summaries in (C. H. Sterling, 2003), and books relevant to the history of software (most of them classics rather than secondary sources) in (C. Sterling & Grier, 2003). Selected secondary sources of various kinds, including web sites, are annotated in (Haigh, 2004b).

Synthetic Histories

Many overviews of the history of computing have been produced over the years. Your starting point should be *Computer: A History of the Information Machine* (Campbell-Kelly & Aspray, 1996). Created with the support of the Sloan foundation, it is written by two of the field's most prominent scholars but intended to be accessible to a general audience. Unlike earlier synthetic accounts it shows the computer as a tool designed to tackle specific applications, going back into history to explore its relationship to earlier office machines, communication technologies, and calculating aids. It mixes the business history of computer firms with the development of key computing technologies. Paul Ceruzzi's *A History of Modern Computing* (P. E. Ceruzzi, 1998) makes a good complement to *Computer*. Ceruzzi's book has less to say about applications, and skips the digital computer's forebears completely to launch the story in the mid-1940s. Ceruzzi provides more detail on the architectural development of computers and better coverage of the minicomputer, which he argues for persuasively as the source of today's personal computing technologies. His book focuses more on technical history and has a somewhat more episodic structure. A more recent summary, intended to be accessible to high school students, is (Swedin, 2005). Several older and journalistic overviews exist, but you will find little cause to consult them.

As historical work necessarily takes place sometime after the events concerned we can trace the spread of computer technology in the changing narratives of the history of computing. The lag appears to be two or three decades. Early work focused on the computer as an experimental calculating machine, and situated it as an evolution of earlier calculating machines. By the 1990s scholars began to explore its administrative use and situate it in the context of earlier technologies like punched card machines and typewriters. *Computer* echoes this perspective. On its publication the book's most novel feature was its insistence on the computer as primarily a tool for administrative coordination rather than scientific calculation. (In other words its framing had caught up with the world of the 1960s, rather than remaining in the 1940s). Although accessible it is not simplistic and nicely summarizes and connects key insights and stories from the secondary literature as it had developed to the early 1990s.

All three books include coverage of personal computing and the internet (particularly in their revised second editions) but this in part a concession to commercial realities. The state of the secondary literature permitted well documented and analytical coverage of events up to the early 1970s, at which point a notable shift in tone and source material occurs. Falling back on conventional wisdom, their authors summarize key events celebrated in popular histories.

Computer works particularly well as a proxy for the strengths and weaknesses of the historical literature in the early 1990s. One of its most striking features is the centrality of the ENIAC to its narrative structure. The earliest chapters consider a whole range of technologies, from file cabinets to telegraphs, used in a whole range of settings. The middle part of the book abruptly shifts to look in detail at ENIAC and a handful of other early experimental machines built during the 1940s in government, academic, and corporate research labs to automate routine calculation. Then the narrative follows digital computers back out into the world as commercial goods. It charts their growing capabilities through three distinct generations of mainframes (culminating in the IBM System 360 range of the 1960s), the evolution of software, the minicomputer industry of the 1970s, and the growing importance of personal computers in the 1980s. This gives the story a distinctive, hourglass shape with ENIAC as the tiny isthmus linking these two worlds. It is what sociologists of scientific knowledge have called an "obligatory passage point" (Callon, 1986) in the history of information technology. ENIAC took that role quite literally in the *Information Age* exhibit shown at the Smithsonian from 1990 to circa 2005. A spacious hall of early information technologies narrowed to a small passageway, in which visitors walked through a partial reconstruction of the machine before emerging into the computer age.

I have argued elsewhere (Haigh, 2001a) that this kind of structure yields a peculiar picture. Understanding the history of information technology does indeed involve looking at the replacement of one technology by another and its use within particular applications. But the most satisfactory way to do this would be to focus on a single social sphere (school, office, hospital, library) and examine changes in the type, use, cultural understanding of, and management of the information technologies found there over a particular period. A one volume history of computer technology or the computer hardware industry would be hefty but conceptually unproblematic, but a one volume synthetic history that takes the use, work, and social dimensions of information technology seriously is probably impossible given the proliferation of computer technology in recent decades. Think of the precursor technologies one would have to integrate. Computers (whether free standing or embedded in consumer electronics) have replaced record players, walkmen, analog television receivers, and video cassette recorders. Books, newspapers, and conventional telephones now appear endangered. In the office they have replaced typewriters, adding machines, bookkeeping and billing machines, duplicating machines, letters, memos and carbon paper. File cabinets are vanishing, and in recent years the amount of paper used in American offices has finally begun to diminish. Computer networks are central to every kind of business operation, and play an increasingly vital role in our social lives and personal communication. Databases, automatic data capture, modeling, and statistical analysis capabilities have transformed practice in almost every area of science. Even the game of solitaire has been remade as a shuffling of mice rather than of playing cards.

As computers are used in more and more ways in more and more social contexts the challenge to synthesis becomes more and more serious. Mahoney expressed (Mahoney, 2005) a similar idea, more elegantly, when he suggested that we should recognize that there is not a single "history of computing" but multiple histories. Furthermore even the technologies themselves will have been literally and metaphorically reconstructed to fit the context at which one is looking. So he titled his article "The Histories of Computing(s)."

Computer Technologies

The abacus is several thousand years old. It was followed by a long series of increasingly complex technologies for counting, adding, and calculating. However I have neither the space nor the expertise to explore in any detail the literature on calculating devices before the electronic computer, a topic worthy of its own length review. These devices loomed large in early overviews of the computer, including the comprehensive and well illustrated (Williams, 1985), but as the field has developed their history has come to seem more distinct. This is probably because fewer people today think of the computer as primarily a device for calculation. As its range of applications has grown, so too has the diversity of its precursors. The primary literature on calculating machines is surveyed in a comprehensive and well illustrated catalog of publications issued before 1955 (Tomash and Williams, 2008). Major museums, including the Smithsonian, the Science Museum in London (J. Pugh & Baxandall, 1975), and the Deutsches Museum have extensive collections of the machines themselves and have played an important part in documenting and preserving their history. I am aware of no comprehensive overview of the recent secondary literature on the topic.

The most famous early devices, and those most clearly related to programmable computers are Charles Babbage's (1791-1871) Difference Engine and Analytical Engine. Neither machine was constructed in his lifetime. Babbage's was omitted entirely from Berkeley's seminal popular discussion of computing (Berkeley, 1949) his failed efforts to build calculating engines having long since slipped from public memory. Within a few years, however, Babbage enjoyed a dramatic surge in his posthumous reputation and was pressed into service as the forgotten inventor of the programmable general purpose computer. The Difference Engine has since been built according to Babbage's plans and can be seen at the Science Museum in London. Its story is told with some zest, along with that of Babbage himself, by the project's leader in (Swade, 2001).. Other difference engines were attempted in Sweden (Lindgren, 1990). The Analytical Engine was intended to store and run programs, but Babbage never finished its design, let alone its construction. Babbage has been the subject of several biographies , most notably (Hyman, 1982). Ada Lovelace (daughter of the famous Lord Byron) wrote a tutorial describing the analytical engine. She has thus been adopted as a rallying point for women in computing and herself received many biographies, of which the least overheated is (Stein, 1985). The letters and papers of both have been published. Babbage is perhaps the only topic in the history of information technology one might plausibly describe as over studied.

The edited volume *Computing Before Computers* (Aspray, 1990b) surveys technologies used for calculation from the abacus through Babbage's uncompleted calculating engines to from punched card machines and electro mechanical calculators of the 1940s. One of its main contributors provides a more detailed exploration of the key computing projects of the 1940s in (P. E. Ceruzzi, 1983), looking at the electro-mechanical automatic calculators built by research groups in Germany, Harvard and Bell Labs as we as the University of Pennsylvania's iconic ENIAC project. The electronic, non-programmable Atanasoff-Berry Computer, constructed at Iowa State University, has also received attention (A. W. Bucks, 1988). Early digital computers were built specifically to handle numerical mathematical calculations. Analog mechanical and electronic computers were a separate genre of machine, used to solve differential equations, model electrical power networks, and simulate flight paths. Though analog computers are generally dismissed merely as precursors to their digital cousins, James Small has shown (Small, 2001) that they remained widely used into the 1960s and supported a thriving network of specialized suppliers and users.

Although scholars and participants have devoted articles (Burks & Burks, 1981) and chapters to ENIAC the only full length study of the project is journalistic (McCartney, 1999). A thorough discussion of the machine and its immediate legacy appears in (Stern, 1981). For a long time it was considered to be the first fully operational programmable electronic computer. In recent decades, however, this title has been claimed by the wartime British Colossus project (B. J. Copeland, 2004; J. Copeland, 2006). Excessive state secrecy meant that its creators had to wait for more than three decades to reveal its capabilities in (Randell, 1980).

The first "stored program" electronic digital computers have also been relatively well covered. Although ENIAC was a high speed electronic computer it did not, as originally constructed, read programs into memory. Configuring it for a new problem involved turning knobs and rewiring patch boards. In contrast, stored program computers treat the program as another kind of data to be loaded into memory for execution. The fundamental design behind modern digital computers is often called "von Neumann architecture," after celebrated mathematician John von Neumann whose "First Draft of a Report on the EDVAC" (von Neumann, 1993) inspired many early computer projects. William Aspray (Aspray, 1990a) used von Neumann's contributions during the 1940s and 1950s to computer design, numerical analysis, computing theory and several other areas as a window into the broader history of computing and applied mathematics during this period.

Many computer building projects sprang up during the late 1940s. These are given thorough summary in the chapters gathered assembled for (Rojas & Hashagen, 2000). The first two stored program computers to become operational were British: a proof-of-concept test system at the University of Manchester and the more powerful EDSAC built by a team at Cambridge University. Manchester's efforts, which gave rise to a tradition of large scale computer development which endured into the 1970s, were profiled in (Lavington, 1998) and have reexamined by David Anderson in a series of recent publications e.g. (Anderson, 2007). The most comprehensive overview of the EDSAC project remains the autobiography of its leader (Wilkes, 1985) though Martin Campbell-Kelly has probed the early development of programming practices around the machine (Campbell-Kelly, 1998).

Electromechanical punched card machines, discussed below in the context of the computer industry and their application to administrative work, are in many ways the most direct technological ancestors of early commercial computers. The most obviously important computer hardware technologies from the 1960s onward are the transistor and the silicon chip. These stories lead us toward the history of electronic engineering and the business history of the electronics industry. Readable, well researched overviews exist of the history of solid state electronics (Riordan & Hoddeson, 1997) and the integrated circuit (T. R. Reid, 2001).Two books combining the structural development of the industry with technical innovations and manufacturing processes are particularly relevant. *To The Digital Age* (Bassett, 2002) tells the story of the development of MOS transistors, their integration onto silicon chips, and the creation of the microprocessor. It uses interviews and archival documents to discuss the contributions of Fairchild, IBM, and Intel. Bassett makes a particular effort to trace the transfer of ideas between firms, and to tie the dramatically different fortunes of IBM and Intel in turning research into products to their different cultures and internal organizations. Christophe Lecuyer's *Making Silicon Valley* (Lecuyer, 2006) documents the rise of the region's industry, looking particularly at the role of military demand and the distinctive network organization of small, specialized producers that sprang up there. Biographies cover the most leading figures in the most famous dynasty within the industry. William Shockley (Shurkin, 2006) was a brilliant crank who invented the transistor and founded Shockley Semiconductor. He proved an abysmal manager, and soon his star employees Robert Noyce (Berlin, 2006) and Gordon E. Moore (creator of an eponymous "Law") left to found Fairchild Semiconductor and, when that got stale, Intel Corporation. Intel established the market for memory chips, built the first microprocessor, and under the leadership of Andy Grove (Tedlow, 2007) came to dominate the market for personal computer processor chips.

Away from this sliver of history and one finds very few histories of computer technologies after the 1950s. Nothing much has been written on computer manufacturing techniques. Components and peripherals have fared little better, though two articles (Tomash & Cohen, 1991a, 1991b) cover the early history of printers, and one book pays particular attention to IBM's early memory technologies (Emerson W Pugh, 1984). No overall history of computer networking technologies has been attempted, although we do have a popular history of fiber optics (Hecht, 1999). The reader looking for a clearly written, accessible and thoughtful overview of the story of the vacuum tube (the basic building block of computer logic in the 1950s), the microprocessor (as opposed to chips in general), disk storage, computer graphics, supercomputers, or minicomputer, operating systems, computer communications, computer architecture, or virtually any other aspect of computer science or computer technology will have to wait.

While almost nothing scholarly has been written on the personal computer industry and its products, the origins of personal and interactive computing technologies have received more attention. Until the mid-1970s it was rarely economical to provide individuals with their own computers. But many aspects of today's computing experience were already available on an experimental basis in the 1960s, including interactive communication and access to shared network resources. Science journalist Mitch Waldrop bit off a big chunk of this history in his book *The Dream Machine* (Waldrop, 2001). He focused on J.C.R. Licklider, a psychology professor at MIT who developed a distinctive vision of "man-computer symbiosis" in which people worked interactively with computers to solve problems. Intended for non-specialists the book sprawls across much of the history of interactive computing, which provides context but blunts the narrative. As the founding director of the Information Processing Techniques Office (IPTO) (Kita, 2003) within the US Government's Advanced Projects Research Agency Licklider had great personal latitude to fund work in this direction, underwriting crucial research on interactive computing and laying the foundations for the experimental ARPANET (seed of the Internet). As well as its now legendary work in support of networking, ARPA supported fundamental research advances in several areas of computer science including operating systems, computer graphics, and artificial intelligence. This story has been told by Arthur Nordberg and Judy O’Neil (Arthur L. Norberg & O'Neill, 1996). As an official history the book is well sourced but rather careful in its conclusions. Between the lines, however, one glimpses a fascinating story of an incestuous and dynamic research culture quite oblivious to today’s worries about research ethics and conflicts of interest.

One of the recipients of IPTO’s largess during the 1960s was Doug Engelbart’s lab at the Stanford Research Institute (Bardini, 2000). Engelbart was an enthusiastic advocate of the power of interactive computers to support daily activities. By 1968 his group had already invented the mouse and, in a famous technology demonstration at the Joint Computer Conference, demonstrated a mouse controlled hypertext system with a text editor able to display information in multiple windows and collapse outline headings into a reshufflable hierarchy.

Researchers from Engelbart’s lab went on to fill key positions in Xerox’s Palo Alto Research Center (PARC) which opened in 1970. Over the next decade its research teams invented many of the fundamental technologies behind the graphical workstations of the 1980s and personal computers of the 1990s, including laser printers, Ethernet, the graphical user interface, What-You-See-Is-What-You-Get editing (displaying editable text with the actual fonts, sizes, and formatting it will have when printed), computer paint programs, and graphical environments for object oriented programming. PARC achieved notoriety as the source of many of the breakthrough ideas commercialized in Apple’s Lisa and Macintosh computers and as an example (Smith & Alexander, 1989) in the business literature of a company that failed to reap the economic benefits of its technological triumphs. Michael A. Hiltzik has provided (Hiltzik, 1999) the most nuanced telling of the PARC story, using interviews with participants to extending the narrative into firm’s commercial product efforts of the early 1980s. Xerox’s Star workstation was intended to put powerful, networked personal computers with big screens and graphical capabilities on the desks of managers, professionals, and secretaries. Hiltzik observes that Xerox earned back its investments in the lab many times over despite never becoming a dominant force in personal computing. The story has also been told by its participants (Goldberg, 1988).The Star failed commercially, but the 1980s did see the emergence of a specialized market for powerful graphical workstations costing tens of thousands of dollars. Firms in this industry played an important role in creating the technologies of today's personal computers, but have so far received no historical attention other than a journalistic book on Sun Microsystems (Southwick, 1999).

Software technologies have suffered a similar neglect, even though the history of the software industry (discussed below) is relatively well documented. Articles, usually by computer scientists or pioneers, have discussed aspects of the history specific software systems. Best developed is the history of programming languages (Sammet, 1969), where a series of three conferences held over the decades by the ACM's Special Interest Group on Programming Languages has yielded a series (Bergin & Gibson, 1996; Wexelblat, 1981) of carefully researched, well edited technical histories authored by the creators of major programming languages. Journalist Steve Lohr produced an accessible and well researched popular history of the topic (Lohr, 2001). Historical efforts have also been made within the software engineering community (Broy & Denert, 2002). Coverage of other areas is at best patchy. The history of formal methods, attempts to mathematically prove the correctness of programs to a logical specification or reason mathematically about their behavior, has been explored by sociologist of science Donald McKenzie (MacKenzie, 2001) and one of its key practitioners (Jones, 2003).

Computer technologies have also been explored by some economic historians. Economic history has increasingly diverged from business history and is largely conducted within the discipline of economics. Authors thus tend to focus on specific technologies as test cases for larger theories, meaning that the same handful of topics such as the QWERTY keyboard layout and its putative inferiority to alternative designs (David, 1985) are debated from a variety of theoretical perspectives.

Computer Science

The first university departments of computer science and accompanying degree programs were created in the 1960s. Computing research had originally been an interdisciplinary venture, carried out by people from varied backgrounds who stumbled into computer projects or found work in computing centers (Aspray, 2000). The push to establish study of the computer and its associated technologies as an autonomous scientific discipline passed a series of milestones, from the establishment of the Association for Computing Machinery in 1947 through the gradual growth of research and teaching in the field during the late 1950s and early 1960s to the chartering of the first department of computer science at Purdue in 1962 (Rice & Rosen, 1994) and the first awarding of a Ph.D. in computer science to Richard Wexelblat at the University of Pennsylvania in 1965. In 1986 the National Science Foundation established its Directorate for Computing & Information Science & Engineering (Harsha, 2004), funding computing research on the basis of its contribution to computer science rather than, as in the 1960s and early 1970s (Aspray & Williams, 1994), supporting computing facilities as means to the ends of other disciplines. Undergraduate enrollment rose rapidly, peaking (until the dot com boom made computer science briefly fashionable again) with forty-two thousand graduating students in 1986 (Fiegener, 2008). Computer science accounted for four percent of all bachelor's degrees granted in the USA that year.

There are two main ways in which to approach this history. The first is to study the institutions of computer science. The major professional societies, leading academic departments, mightiest corporate research labs, and key funding bodies all deserve in-depth analysis. One might also hope for the creation of synthetic histories that weave together these different strands to show their interrelationship. So far we have only a few bits and pieces of the overall picture. William Aspray has published seminal articles on the history of early computing departments (Aspray, 2000) and the University of Pittsburgh's information science program (Aspray, 1999). The history of the Association for Computing Machinery appears as a subsidiary theme in the work of several scholars (Haigh, Kaplan, & Seib, 2007) and has been sketched by several insiders. The recent transfer of the association's records to the Charles Babbage Institute is likely to spur additional work in this area. Little has been written about the history of other associations such as the IEEE Computer Society (and its precursors) and the Society for Industrial and Applied Mathematics. The history of computer science funding agencies is relatively well developed, mainly because government bodies sometimes commission their own histories. A lengthy article covers the early history of NSF funding for computer science (Aspray & Williams, 1994) and books on ARPA's support for key computing technologies (Arthur L. Norberg & O'Neill, 1996) and the Strategic Computing initiative of the 1990s (Roland & Shiman, 2002) round out the picture. The latter began as an authorized history but was completed independently and gives a fascinating and well conceptualized account of the interplay of politics, empire-building administrators and grant-hungry researchers. Corporate labs have been much less well documented, with the exception of the Xerox PARC facility (discussed below) which looms large in histories of personal computing.

The other main approach is to look at the evolving content of computer science research. This might be tackled as an exercise in intellectual history in the manner of traditional internalist history of science, looking at the rise and fall of schools of thought and the succession of key problems and areas of interest. This requires the researcher to develop a high degree of expertise in the discipline as understood during the time period in question, and so in many fields work of this kind is tackled more by members of the discipline in question rather than by Ph.D. historians. One might also imagine more externalist histories of computer science, in which shifts in the style or content of research are explained with reference to politics, funding priorities, or attempts to legitimate the discipline as academically respectable.

Computer science has not, as a discipline, made a significant commitment to history and historical material is almost entirely absent from the curriculum. This contrasts with many professional fields such as business, medicine, and indeed librarianship where historical research and teaching has traditionally taken place within the discipline (although even there it is increasingly losing ground). While several computing researchers of the pioneer generation made significant early contributions to the history of computing, younger faculty members generally cannot afford to devote time to such a marginal topic. No Ph.D. historian has ever been hired to a computer science faculty in the United States. Michael Mahoney was the only historian to attempt a broad intellectual history of theoretical computer science, and while his effort yielded some suggestive and intellectually intimidating articles (Mahoney, 1997; Mahoney, 2002) he did not produce a monograph on the topic.

The biography is an important genre within the history of science. Only mathematician and computing theory pioneer Alan Turing has so far received much attention here, most notably in the monumental biography *Alan Turing: The Enigma of Intelligence* (Hodges, 1983). In popular culture Turing has been computer science's breakout hit as genius, oppressed homosexual, and war-winning code breaker. Grace Hopper, who led important early work on programming languages in the 1950s before becoming a manager of computing projects for the U.S. Navy, is the poster lady for women in computing and been profiled in two biographies (Beyer, 2009; K. B. Williams, 2004). In contrast the best known academic computer scientists such as Richard Hamming, Marvin Minsky, Edsger Dijkstra, Donald E. Knuth, and C.A.R. Hoare are yet to receive full length biographies.

Business Histories: Mainframes and Minicomputer Producers

The development of the computer industry up to the early 1970s is, along with the development of early one-off computers, one of the best documented corners of the history of information technology. The computer industry features prominently in recent overviews of the history of computing, and has received a focused summary (J. Yost, 2005). *Before the Computer* (Cortada, 1993) puts the industry into its historical context, showing the extent to which the mainframe computer industry grew out of the earlier office machine industry.Hell Likewise (Arthur L Norberg, 1990) showed the importance of punched card machine companies to scientific computing practice even before the development of electronic computers.

Until the 1980s the global computer industry was dominated by IBM, which maintained a market share around seventy five percent and enjoyed a similar share of the books devoted to the computer business. While dozens of books by journalists and popular writers cover IBM's early history they recycle a fairly small pool of incidents and anecdotes. Early accounts (Bedlen & Bedlen, 1962) focused on the charismatic autocrat Thomas J. Watson who led the firm (and its precursor) from 1914 to the 1950s. Watson's gift for self promotion ensured that he was famous as a business visionary and friend of presidents long before his company reached the top echelons of American business. Watson's complex relationship with his son and successor, Thomas Watson, Jr. and other family members has provided grist for more recent work (Tedlow, 2003).

Two books on IBM stand out. Emerson W. Pugh, a former IBM insider, has written a careful and thoughtful overview (Emerson W. Pugh, 1994) of the firm's development, based on archival sources, which goes beyond anecdotes to expose relationships between the IBM's market positions, technologies, and internal dynamics. Watson Jr.'s autobiography (Watson & Petre, 1990) is a model of its kind, and skillfully interweaves his personal story with the development of the firm. More recently, scholars have begun to put Watson's management style into broader historical contexts, such as the development of the American industrial style of welfare capitalism (Stebenne, 2005). Drawing on business theory, the firm's success has been explained (Usselman, 1993) in terms of its development of organizational capabilities appropriate to market needs.

Anyone interested in the rest of the industry will find rather slim pickings in the current academic literature. In fact there only two scholarly monographs devoted to individual companies other than IBM. One is the award winning *ICL: A Technical and Business History* (Campbell-Kelly, 1989). The scope of the book is broader than one might suppose, as ICL was created by government order in the 1960s as an amalgamation of almost the entire British computer industry. Arthur Norberg followed this with an examination (Arthur L Norberg, 2005) of two of the first startup companies in the industry (The Eckert-Machley Computer Company and Engineering Research Associates) and their merger as the foundation of Univac, the number two player in the early computer industry.

National Cash Register was an important force in the computing market, but its history has been told primarily as an adjunct to IBM's because Watson Sr. got his start in the office machine business there. The only full length published history is a memoir credited to a former executive (Allyn, 1967) which says almost nothing about the computer era.[3] General Electric's years in the mainframe business provide a sad tale told so far only by its participants (Lee, 1995; Lee & Snively, 2000; Oldfield, 1996).

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[3] A four volume history of NCR was prepared and given to employees on the occasion of the firm's 100th anniversary in 1994. The third volume, "NCR: 1952-1984: The Computer Age" apparently deals with this topic.

Almost nothing has been written about the post-War history of calculating machine giant Burroughs, which carved out a respectable niche in the computer industry. Likewise no overall histories have been produced of the role of Xerox, RCA or Honeywell in the mainframe markets of the 1960s and 1970s, or of the history of Univac after the 1950s. I am unaware of any major English language histories of European or Asian computer companies. Shane Greenstein has looked at the economic history of a number of aspects of computing, including the mainframe market (Greenstein & Wade, 1998).

Control Data Corporation pioneered the market for scientific supercomputers and dominated it during the 1960s. The firm's extensive archives are at the Charles Babbage Institute but have so far seen little use, so those interested in the firm will find little more than a retrospective musing on its management secrets (Price, 2005). Its star designer, Seymour Cray, went on to achieve fame through two eponymous companies which built the world's fastest computers during the 1970s and 80s. A typically breathless journalistic account, *The Supermen* (Murray, 1997) tells this story, as does a scholarly article (Elzen & MacKenzie, 1994).

Digital Equipment Corporation grew from a specialized producer of laboratory control equipment to pioneer the market for minicomputers in the 1960s, diversifying into mainframes and office computers in the 1970s. By the 1980s it was second only to IBM in the global computer market, with a thriving network of research and development centers. DEC's was sketched in a nicely produced and relentlessly upbeat corporate history written by its then archivist (Pearson, 1992) and a hagiographic biography of its founder (Harrar & Rifkin, 1988). A more recent book written by former employees focused on its "legacies" (Schein, 2003), some of its early history was documented in a self published memoir (Ornstein, 2002) and a coffee table book of pictures (Earls, 2004). Its main rival in the minicomputer business, Data General, received a wonderfully vivid bottom-up portrait in *The Soul of a New Machine* (Kidder, 1981) but its history remains undocumented.

Work so far on the history of the computer industry gives a reasonably good sense of its important products and technologies and of the strategies of some of its key firms. Future research should address limitations of perspective as well as extending coverage to companies and national industries so far been neglected. We have little sense of what it was like to work in these firms as anything other than an engineer or executive. Nothing has been written about manufacturing processes, production engineering, or assembly line work. And, although computer firms became emblems of the new high technology economy by the 1960s and had been pioneering the personnel policies of “welfare capitalism” since the 1920s, no major studies of the industry have yet explored its role as the model for a new kind of industrial culture.

Business Histories: Personal Computing

The early history of the personal computer industry is another topic so far untouched by scholars. *Fire in the Valley*, in its first edition (Freiberger & Swaine, 1984) gave a fresh and immediate account of the industry’s idiosyncratic origins and the travails of briefly successful firms during the 1970s. A revised edition adds coverage of later events but the new material is patchy and dilutes the original’s charm. Events of the 1980s are covered best in *Accidental Empires* (Cringely, 1992). Written by the gossip columnist of a computer newspaper, the book provides the expected scuttlebutt on the personalities of industry celebrities such as Bill Gates and Steve Jobs alongside the development of crucial products such as the Apple II, Lotus 1-2-3, PostScript, and IBM PC compatible BIOS. But it is also unexpectedly thoughtful, convincingly linking their foibles to the structural development of the hardware and software industries and providing some exceptionally clear analysis of the nature of platform-based competition. Its PBS television adaptation preserved some of these qualities.

The idea of computers as tools for some kind of personal liberation, nurtured by Licklider and Engelbart during the 1960s, was also channeled into the early development of the personal computer. A cluster of new technologies including RAM chips, microprocessors and floppy disk drives made it possible for electronics hobbyists to design and build cheap computers using readily available components. The more entrepreneurial of these hobbyists founded companies to sell peripherals, software, and preassembled computers to their fellow enthusiasts. The freshest and most influential account of this movement was given by technology journalist Steven Levy in his wonderfully observed book *Hackers* (Levy, 1984). John Markoff, also a journalist, retraced much of the same ground in his more recent *What the Dormouse Said* (Markoff, 2005) but the book suffers in comparison from a meandering narrative and his failure to clearly conceptualize the counterculture.

One company founded by computing hobbyists, Apple Computer, had become the dominant force in the American personal computer industry by the end of the 1970s. Despite subsequent travails it endures today as one of the world's most successful technology companies. As with Microsoft space does not permit anything like a full listing of the many books journalists have written about this company, its corporate culture, and its mercurial leader Steve Jobs. Some are more interesting and more reliable than others, but none are particularly ambitious intellectually or do much to frame the personalities, triumphs, and mishaps of the company in a broader context. Readers interested in its earlier history and the introduction of the Macintosh will find *The Little Kingdom* (Moritz, 1984) indispensable. Levy's account of the development of the Macintosh, *Insanely Great* (Levy, 1994) is not a patch on his earlier book *Hackers* but was informed by input from within the design team. One key member of that team offers his own recollections in blog-turned-book (Hertzfeld, 2004). Hatchet jobs are also plentiful, and the firm's stumbles and oddities give their authors much material to work with. The best supported is a memoir (Amelio & Simon, 1998) by the ill-fated Gil Amelio, who briefly led the company during its mid-1990s nadir. This chronicle of disaster and frustration exerts a certain uneasy fascination. Apple's corporate archives are now available for scholarly use at Stanford University, so one can at least hope that some brave historian will soon delve into this material in search of less familiar stories.

No other personal computer company has inspired anything like the same outpouring of material. At one time or another Atari (S. Cohen, 1984), Texas Instruments and Radio Shack (Kornfeld, 1997) held significant chunks of the American home computer market but none seems to have received significant historical attention. Commodore, which produced the best selling computer model of all time (the Commodore 64) has been largely ignored by historians and journalists alike because its breakthrough hit was an inexpensive machine for home use. This has been redressed in (Bagnall, 2005). This lengthy and unashamedly partisan tome was self published and could have used an editor, but its scope and depth of research make it the most ambitious history to date of a home computer company. It captures the flavor of the era and culture of the company as well as many details of its technical accomplishments. The first substantial work on the history of personal computing is now arriving in dissertation form from a new generation of scholars (Lean, 2008; Veraart, 2008).

In 1981 IBM released its Personal Computer (Chposky & Leonsis, 1988), rapidly establishing market dominance and setting a powerful de facto standard for the industry just as it had previously done for mainframe computers. But by the 1990s the personal computer industry has evolved to a quite different structure. It became a complex ecosystem in which Microsoft and Intel hold strategic power over two key components of the overall system, personal computer "manufacturers" did little more than screw together, market, and support commodity computers built from a dozen or so major components, and these components were designed by anonymous, specialized firms in places like Korea and Taiwan. There was a standard design, but it was neither imposed by a single company nor defined by a formal process. This will surely make for a shelf full of fascinating histories, but so far we have only a provocative sketch (Sumner, 2008). Firms like Dell (Dell & Freedman, 1999) did no actual engineering and so will need to be analyzed in rather different ways from earlier computer companies.

Those curious about the development of handheld computers will find that (Kaplan, 1994), a memoir of the ill-fated tablet computing pioneer GO Corporation, provides a fascinating picture of the Silicon Valley venture capital and startup company rituals of the early 1990s and of the challenges faced in competing directly with Microsoft in this era. The pen computing concept eventually took off with the Palm Pilot, a geek icon during the Internet boom years of the late 1990s. Its story is cleanly but blandly recounted in (Butler & Pogue, 2002). Cellphones have developed over the past decade into versatile computing platforms, but no history yet covers this.

How will the stories historians eventually get round to telling about the personal computer likely to differ from those already spun by journalists and enthusiasts? A look at the development of corresponding literatures in other fields suggests four important areas. First, historians are likely to broaden the narrative beyond Silicon Valley and the handful of other firms (such as Microsoft) included in popular accounts. Personal computers, and home computers, spread around the US and around the world in a process that cannot be fully understood without a much bigger canvas. Second, historians will be interested in the users of personal computer technologies as well as their producers. In this case the two categories can be rather porous anyway, as enthusiasts built peripherals or wrote programs thus using one kind of technology to create another. Users created their own meanings and applications for standard technologies such as the Apple II, transforming it into an educational tool, piece of lab equipment, games console or financial workstation. Third, historians will be interested in the web of social groups and communities that sprang up around the new technologies: user groups, specialist dealers, newsletters, bulletin boards, and so on. These networks have been probed for other technologies of the era (Greenberg, 2008) but not yet for the personal computer. Finally, historians will not be satisfied to explain the personal computer's rise as the inevitable consequence of the geeky genius of its creators. They will look at the social and economic context of the late 1970s and early 1980s, particularly the power of notions such as the "post industrial society" and "microelectronic revolution" and the symbolic position of computer technology as counterbalance to the crumbling of traditional industries in the face of Asian competition.

Business Histories: Software Producers

In one sense the software industry can be traced back to the 1950s, as early computer users often hired specialized firms to assist with programming work or provide other computer-related services. For example much of the work on the very first administrative computing application in the United States, a payroll system for General Electric's appliance plant in Louisville, Kentucky, was handled by members of the accounting firm Arthur Andersen. New firms such as the Systems Development Corporate sprang up at about the same time to handle system development chores for the burgeoning array of cold war computer systems. The term software gained currency in the early 1960s (Haigh, 2002), originally to describe everything beyond the hardware itself that a computer manufacturer would supply with a machine (programs, documentation, services, etc). Only in the late 1960s, however, did a market develop for what we would today think of as software: standardized computer programs licensed to many customers and flexible enough to be configured to match their needs without being reprogrammed. Pioneering firms of the late-1960s focused primarily on systems software tools such as utilities for programmers. The market for applications programs, such as standard payroll and accounting packages, followed a little later. By the late-1970s the mainframe software industry was well established, and a decade later the fast growing personal computer industry was producing its own stars.

The earliest software companies such as the Systems Development Corporation (Baum, 1981) and Informatics received book length histories in the 1980s. Informatics General was the world's largest independent software company for much of the 1960s and 1970s, beginning as a contractor on government projects but diversifying into other areas (Bauer, 1996). Its Mark IV software package (Postley, 1998) was the first packaged software to reach ten million dollars in cumulative sales. The firm commissioned a thorough and professionally produced history (Forman, 1984). Issued just as the company was being broken up it is impossible to buy, but can easily be obtained via interlibrary loan.

Martin Campbell-Kelly has surveyed the development of historical work on the software (Campbell-Kelly, 2007a). By the late 1990s historians of information technology were uncomfortably aware that very little work to date had addressed any aspect of the history of software. A conference in Paderborn, Germany led to a book (Hashagen, Keil-Slawik, & Norberg, 2002) intended to showcase promising approaches, record debates, and lay out some kind of "research agenda" for studying software. This is still the best starting point for this topic.

Recent work has provided relatively good coverage of the structural evolution of the packaged software industry. Campbell-Kelly's implausibly titled *From Airline Reservations to Sonic the Hedgehog* (Campbell-Kelly, 2003) is the outstanding contribution here, tracing the development of the software industry from consulting and services firms through the mainframe era and on into the mass market merchandising of the personal computer software industry. He strives to provide coverage of the major companies and market niches in rough proportion to their economic importance, inserting anecdotes and capsule biographies to enliven a narrative driven by statistics and market share reports. The economic history of the software industry is explored in (Mowery, 1995), while a survey with particular attention to the services side of the industry is presented in (J. R. Yost, 2005).

Campbell-Kelly's book is focused on the structure of the software industry, and because of its broad scope can say little about the development of software technologies, user experiences, or the evolution of particular kinds of computer program. These topics require more tightly focused historical studies, some which are beginning to appear in article form, as usual with a lag of twenty to thirty years. The Software History SIG of the Computer History Museum (formerly the Software History Center) has been active in preserving the history of the early software industry. A series of workshops addressing different aspects of its history have been held from 2002 onwards, including oral history interviews and roundtable discussions (Johnson, 2003) transcribed and placed online. This work has been showcased a special issue of IEEE Annals of the History of Computing (2001) and a series of subsequent articles in the same venue. Three special issues of IEEE Annals of the History of Computing, edited by Burton Grad of the Software History SIG, have addressed key software genres. Campbell-Kelly himself has written about the development of spreadsheet programs (Campbell-Kelly, 2007b), anchoring a special issue on the topic. Tim Bergin and I have carried out a similar role in issues on the early development of word processing (Bergin, 2006a, 2006b; Haigh, 2006) and data base management systems (Bergin & Haigh, 2009; Haigh, 2009). These issues also featured articles by participants, such as the authors of important programs like VisiCalc and WordStar and the leaders of companies that developed and published them.

In the absence of scholarly histories one turns as always to memoirs and books by business journalists. One could fill a fairly hefty bookcase using nothing but books on Bill Gates and Microsoft. But doing so would be a mistake, as most retread the same worn anecdotes. Of the biographies, the early *HardDrive* (Wallace, 1992) is among the freshest, covering the company's origins and its many troubled products of the 1980s. Its sketch of Gates as a brilliant, pathologically competitive, and socially maladjusted man-boy crystallized his public image. The more recently updated *Gates* (Manes & Andrews, 2002) covers developments through the late-1990s. By this point Gates' story and that of his firm were diverging, as Gates married, mellowed, and shifted his attentions to philanthropy while

Microsoft hunkered down into a more bureaucratic and conservative phase of its existence. Michael Cusumano's book *Microsoft Secrets* (Cusumano, 1995) was the among first to consider the firm as more than just a backdrop for Gates, digging into its corporate culture, marketing, and project management practices during its rise to industry dominance. Today's Windows products are based not on the ancient code base of MS-DOS and Windows 3.0 but on Windows NT, designed in the early 1990s by minicomputer operating system specialist David Cutler as an industrial strength alternative. Its creation was recorded by journalist G. Pascal Zachary (Zachary, 1994). Around the same time Microsoft made a major expansion into multimedia publishing, adding CD-ROM products such as the Expedia encyclopedia. Fred Moody spent a year embedded in a multimedia product team, and his book (Moody, 1995) gives a vivid look at the firm's evolving culture and efforts to blend programming and creative content development. The company's next big challenge, the Internet, prompted serious internal divides and some fundamental shifts in strategy and organization. David Bank, a reporter for the Wall Street Journal, presented a well researched and readable account of this traumatic era in *Breaking Windows* (Bank, 2001).

Other major software firms of the personal computer era such as Novell, Lotus, Borland, Ashton-Tate have left remarkably little coverage of this kind. The main exceptions to date are a memoir (Peterson, 1994) by an executive of the business responsible for the once-ubiquitous WordPerfect and a tell-all memoir cum business advice book (Ferguson, 1999) from an entrepreneur who developed the FrontPage web editing software and sold his firm to Microsoft. Enterprise software firms work outside the direct experience of most people, so while today's business software giants such as Oracle and SAP are almost as large as Microsoft, and more strategically important to the operation of the economy, they have received nothing like the same attention. Oracle is at least blessed with Larry Ellison, whose widely reported wealth, arrogance, and love of expensive things have caught the attention of several biographers. Of these *Softwar* (Symonds & Ellison, 2003) offers the best coverage of the firm's culture and technologies and, in a novel twist, is footnoted with asides from Ellison himself. The book has about one hundred pages of company history and several times that volume of badly dated celebrity style profiling of Ellison's personal life and blow-by-blow reportage of industry politics cira 2000. Oracle's onetime competitor in the data base management systems business, Informix, is the subject of a memoir (Martin, 2005) dealing largely with the circumstances that sent its chief executive to prison. SAP, provider of the world's most successful suite of administrative applications, enjoys an uninspired journalistic profile (Meissner, 2000) and a solid scholarly article (Leimbach, 2008).

National and International Stories

American scholars tend to view the history of information technology as a fundamentally American narrative. The US is the only country with a sufficiently central role in most of areas of information technology that a coherent (if skewed) overall history of computing can, and often has, been written with minimal reference to the world outside its borders. There are a few Englishmen who force their way into the narrative: Charles Babbage, Alan Turing, the teams behind the Manchester Mark 1 and the EDSAC, the LEO group that pioneered administrative computing, and Tim Berners-Lee. Konrad Zuse flies the flag for Germany. Jacquard's automatic loom earns France a paragraph somewhere in an early chapter. But these can be dismissed in passing as brilliant figures whose seminal technical accomplishments quickly passed into the hands of Americans for practical exploitation. The history of personal computing, in particular, is told by Americans entirely without reference to the existence of a world beyond the oceans, or in most cases beyond the Valley.

Historians based in the United States have therefore been much less likely than those working in other countries to attempt to isolate peculiarities of their own national experience or relate the development of information technology industries to the influence of government policy. One exception is (Flamm, 1988), which covers the early history of the computer industry and its technologies with close attention to the sources and influence of state funding. Another is (Alfred D. Chandler & Cortada, 2000), an edited volume exploring the application of information technology (including older systems such as mail delivery) within American society. The chapters dealing with earlier developments are, unfortunately for our purposes, noticeably stronger than those addressing the computer era. Policy perspectives, mostly on the relationship of governmental actions to the development of national computer industries, are presented in (Coopey, 2004).

Scholars in other countries have tended to focus on national narratives, generally framed with perceived differences between local developments and those in America. To date the United Kingdom, Germany, France, Japan, Canada, the Netherlands, the USSR, and the Nordic countries have the best developed historical literatures. Histories of national computing, unfortunately for the monoglot, tend to be written in national languages. Historians have largely resisted the trend among scientists of publishing primarily in English, perhaps because of the richer vocabulary required. My discussion here is confined to English-language publication.

As few companies had large enough national markets to support a fully developed indigenous computer industry national narratives tend to focus on quite short historical periods and follow a similar course whether the country in question is the UK, France, the Netherlands, Canada, the USSR, or Czechoslovakia. Resourceful teams working at national scientific institutes produce experimental computers. Local firms enjoy some success in producing machines based on indigenous designs, but at some point in the 1960s are either driven out of business, acquired by American companies, or merged into state sponsored national champions intended to enjoy economies of scale. Researchers in academic and corporate centers continue to do great work, but the benefits of their breakthroughs are largely appropriated by foreign firms. Yet local IT companies continue to thrive in particular niches, such as business software or embedded system design. National computing stories thus tend to have a rather melancholy tone, in which flurries of success are followed by a painful declines and squandered opportunities. IBM and other American firms have thus been seen as the enemy, a kind of wave that eventually sweeps away local capabilities. Recent work (Medina, 2008; Schlombs, 2008) has begun to complicate this picture, looking at the place of local branches of American firms within national computing cultures and challenging the idea of IBM as a monolithic and alien force. Asian counties may, of course, have different national master narratives of computing in which they become involved later but, in many case, enjoy considerable success with the development of hardware and electronics.

Many works on aspects of the British experience are discussed elsewhere in this chapter. Computer technology occupies a fairly prominent place in British collective memory, as an exemplar of national decline in which the spectacular innovations of the 1940s somehow entitled Britain to a dominant role in the international computer industry which was then squandered through the incompetence of business and government leaders. This idea receives its clearest examination in (Hendry, 1990). However this "declinist" tendency in British twentieth century historiography has itself been critiqued recently (Tomlinson, 2009) as a skewed perspective based on myths held during the period and the hangover of empire.

John Vardalas has produced a fascinating and multifaceted examination of Canadian computing (Vardalas, 2001). It covers topics from the first academic use of computing in Canada through military electronic projects, to civilian applications in business. His integration of these different perspectives and situation of the Canadian story in an international perspective makes this the best developed national story to date.

Soviet computing has been treated in two major English-language publications. One (Gerovitch, 2002) is focused on cybernetics, which came late to the Soviet world but endured as a rubric for computer applications long after it lapsed into eccentric marginality in the West. Gerovitch focuses on the relationship of Soviet science and its discourse to politics and its institutions. The other (Malinovsky & Fitzpatrick, 2010) is an edited translation of historical and autobiographical work by Boris N. Malinovsky whose career ran from a junior role on very first Soviet computer project, through designing important minicomputers in the 1960s for industrial control and scientific applications, to work on early personal computers in the 1970s and 1980s. Soviet computing has also been explored in a number of articles, generally focused on specific early projects, such as (Ichikawa, 2006) and (Crowe & Goodman, 1994).

A significant amount has been published on the history of French computing, although this does not include an English language overview of the national story. The best starting point is a series of special issues of *IEEE Annals of the History of Computing* edited by Pierre E. Mounier-Kuhn in 1989 and

1990.[4] These included coverage of inventors, companies, computers and institutions. Mounier-Kuhn has continued to write prolifically on many aspects of the history of computing in France.

The Dutch literature is also well developed. Its national story follows the usual pattern (Wit, 1997), including seminal research at the Mathematisch Centrum, commercialized by the plucky but doomed firm Electrologica. Computer building efforts by electronics giant Philips were also unsuccessful. However the Netherlands also has an exceptionally well developed literature on the use of computers by government and industry, such as. (Ende, 1995) and (O. de Wit, van Den Ende, Schot, & van Oost, 2002). This includes recent work on personal computing (Veraart, 2008) – a topic so far neglected by American scholars. I have been unable to find an English language overview of computing in Germany, though a number of focused articles have been published including those in a special issue of *IEEE Annals of the History of Computing* devoted to the IBM Boeblingen Laboratory (July 2004).

The Nordic countries have also produced a disproportionately diverse literature on the history of information technology, produced by scholars from a range of disciplinary backgrounds. The best introduction is (Bubenko, Impagliazzo, & Solvberg, 2005), based on a 2003 conference. A second volume is forthcoming. This work, too, blends concern with the traditional stories of pioneers and early machines with a refreshing interest in issues of computer use, personal computing, and professional identity (Vehvilainen, 1999).

Not much is written in English and easily accessible on the history of information technology in Japan. An overview of the early computer industry is given in (Takahasi, 1996). A recent special issue (Nandasara & Mikami, 2009) has explored the evolution of computer support for Asian language, a fascinating example of the barriers posed by local culture to the diffusion of information technology and the huge amount of work necessary to reconfigure supposedly universal devices. Discussion of Latin America is still more sparse, though (Medina, 2006) explores the special role of computer networks and cybernetics to the economic plans of Chile's Allende government.

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[4] This encompassed the whole of Volume 11, Issue 4 and a several articles in each issue of Volume 12.

International and comparative studies remain quite rare. Alfred Chandler (Alfred Dupont Chandler, Hikino, & Nordenflycht, 2001) has considered the history of the computer industry from a comparative international perspective, and James Cortada has sketched (Cortada, 2004) some of the issues involved in international computing history. In the context of European technology policy, some attention has been paid (Kranakis, 2004) to the failed international consortium Unidata intended to unify Europe's leading mainframe producers in the 1970s.

A promising collaborative project is currently underway in the area. During the 1960s the Soviet Union launched a massive project across the COMECON countries to replace existing mainframe designs with a new, compatible architecture copied from IBM's System 360 range. This history is currently being explored from several national and international perspectives.

Networking Technologies and Applications

The rise of the computer networks and application, in particular the World Wide Web, inspired a hunt for historical precedents. A great deal has been written about engineer and science policy pioneer Vannevar Bush and his magazine article (Bush, 1945) describing imaginary machine known as the Memex. This was to be a desk equipped with a screen, a camera, and an enormous microfilm storage capacity. Users could retrieve existing articles and construct "associative trails" linking related items (p.124). The Memex would never have been practical with the specific technologies proposed by Bush, but his vision of an extensible network of links tying together a huge data base of text and graphics was a major influence on later work (Nyce & Kahn, 1991). Unusually for a non-existent machine the Memex has spawned an intimidating large body of literature, including the unusual honor of its own ARIST chapter (Houston & Harmon, 2007) the existence of which relieves me of the need to attempt a full reckoning here. The Memex, like Babbage, is one of those few topics in the history of information technology about which more research is not urgently needed. Other scholars have mooted similar grand projects as antecedents of the World Wide Web – Martin Campbell-Kelly (Campbell-Kelly & Aspray, 1996) is partial to the idea of a "world brain" proposed by H.G. Wells (Wells, 1938), a concept explored in more detail by Boyd Rayward (W Boyd Rayward, 1999). Rayward has also (W. Boyd Rayward, 1998) analyzed Paul Otlet’s efforts to catalog and cross reference the world’s knowledge as a precursor of hypertext.

The modern concept of hypertext, as a set of active links embedded in electronic text, can be traced to Ted Nelson who built a reputation as a brilliant but idiosyncratic computer visionary. Nelson invented the concept of hypertext in the early 1960s and used a book entitled Computer Lib/Dream Machines (Nelson, 1974) to promote his planned electronic publishing systems as the foundation for new kinds of artistic creativity. Nelson struggled for years, and with the assistance of several companies and groups of supporters, to deliver his long promised Xanadu system. In the meantime the World Wide Web created a real global hypertext network, though one that failed to support many of Nelson’s original concepts. No historian has yet tackled this story, though the Xanadu’s tortuous progression was sketched in a memorable article (Wolf, 1995) in *Wired Magazine*.

The Internet’s underlying technical structure evolved from ARPANET, a network constructed in the late 1960s and early 1970s for the use of computing researchers funded by the American military research agency ARPA. This was the first large scale network designed around packet switching technology, in which data was bundled into small packets for separate routing over the network rather than being sent over a dedicated electrical circuit from source to destination as had been the practice with the telephone system and earlier computer networks. The development of the ARPANET and its evolution into the early, non-commercial incarnation of the Internet has been explored by Janet Abbate in *Inventing the Internet* (Abbate, 1999). Concise but clear and well researched the book outlines the technical and institutional stories. Its treatment of network users is particularly revealing, illuminating the coevolution of infrastructure and applications. Abbate demonstrates that email, rather than the intended application of logging into remote computers, emerged as the driving force behind the network’s success. A chapter in (Arthur L. Norberg & O'Neill, 1996) is devoted to the institutional story of ARPA’s support for this and other networking initiatives. The other full length history of the Internet, *Where Wizards Stay*

Up Late (Hafner & Lyon, 1998) is readable and somewhat more thoughtful than one might expect from its title but focuses more on personalities and anecdotes than context or analysis.

Historians have also uncovered two European networks constructed in the 1970s around packet switching technology. A British national network was proposed by Donald Davies prior to the creation of ARPANET but was initially realized with only one computer which unfortunately limited its impact (Campbell-Kelly, 1988). Davies also invented the term packet switching. The French Cyclades network was built in the early 1970s and introduced several important advances. In contrast the Soviet Union did not build a national network despite, or as one historian has argued because of, its political commitment to cybernetic central control of the economy (Gerovitch, 2008).

A range of other networks served various niche groups. Usenet (later UUCPNET) was developed in 1979 for users of Unix-based computers. It employed a system of automatic file transfers to synchronize files and pass messages between computers. This powered the popular system of Usenet Newsgroups, which by the early 1990s had transitioned to the Internet. BITNET linked American universities of the 1980s, primarily those using IBM mainframes. LISTSERV software for the maintenance of email discussion and announcement lists was pioneered on BITNET (Grier & Campbell, 2000). Hobbyists created thousands of amateur bulletin board servers, which were linked to provide email and file exchange capabilities via FidoNet. These systems have slipped rapidly from general awareness, but almost nothing has been published so far on their history. Online database publishing has its own separate history, explored with remarkable detail and comprehensiveness in its infancy during the 1960s and early 1970s in (Bourne & Hahn, 2003).

A number of commercial networks sprang up during the 1980s. The best documented of these was the WELL (Hafner, 1995) a rather highbrow system tied to Whole Earth Catalog founder Stewart Brand. Technology writer Howard Rheingold used his experiences on the WELL to popularize the idea of the virtual community in his influential book (Rheingold, 1993) of the same name. Its history is explored by Fred Turner in his book on Brand and his projects (Turner, 2006).

In contrast the leading commercial networks of the period have seen little attention. In the late 1970s and early 1980s a wave of enthusiasm for videotext systems swept the western world. These combined cheap terminals, slow modems and chunky displays (often via a standard television set) to offer affordable access to computer networks. Videotext was intended to provide the masses with online shopping, stock trading, reference materials, email and entertainment. Dozens of national and commercial systems were launched and widely ignored by their putative users. Only in France, where France Telecom stopped printing telephone directories and gave away its unique Minitel terminals instead did this push to bring ordinary people online succeed. No general history of Videotext has yet been written, though Minitel's success has received some examination (Fletcher, 2002).

The failure of videotext was followed from the mid-1980s by the gradual success of a less ambitious set of services, aimed at the niche market of personal computer enthusiasts and small business users. They included BIX (the Byte Information eXchange), Compuserve, GEnie, and Prodigy. These services provided data base access, technical support forums, file downloads, games, and other services. AOL, which originated as a set of specialized services aimed at users of particular computer models, grew rapidly in the 1990s to become the biggest of these online services as its frenetic marketing activities succeeded in bringing a mass audience online. This topic too has been neglected by historians, although AOL was the subject of a number of books by business journalists drawn by its meteoric rise and audacious takeover of media giant Time Warner. Of these the gushingly titled *aol.com: How Steve Case Beat Bill Gates, Nailed the Netheads, and Made Millions in the War for the Web* (Swisher, 1998) provides the most thorough history of the industry's development.

By the end of the 1990s the Internet had unexpectedly supplanted these proprietary networks. The initial commercialization of internet infrastructure is discussed in (Abbate, 2010) and the emergence of the commercial internet access industry in (Greenstein, 2001a, 2001b). This abrupt transition of the Internet from academic backwater to universal infrastructure has tended to make people forget that most networking experts of the early 1990s, including many of those running the Internet itself, believed that the future lay with a quite different set of network protocols. Conceptual work from the 1970s led to the development of the Open Systems Interconnection seven layer model and a massive international standards effort to develop universal protocols for applications such as file transfer and email within this framework. This story has received some historical attention (Abbate, 1999; Russell, 2006) but lacks a definitive account.

The World Wide Web originated in the early 1990s as a simple application based on the existing infrastructure of the Internet's applications and protocols. Like other developments of the 1980s and 1990s this falls into a kind of historiographic dead zone in which it is sufficiently remote for journalists and policy scholars to have moved on but not yet far enough removed to attract the attention of many historians. We do have two histories of the web, both based on insider accounts. Tim Berners-Lee, the web's inventor, partnered with a journalist to produce *Weaving the Web* (Berners-Lee & Fischetti, 1999), a light but vivid memoir of its origins. Robert Cailliau, a former colleague of Berners-Lee at CERN and a key early supporter of the project, has presented a broader and deeper account of the web's origins (Gillies & Cailliau, 2000) including a revealing summary of the lab's internal functioning and a detailed history of the first few years of web browser and server development outside CERN. Other Internet applications and their associated protocols (email, news, file transfer and the like) have received little historical analysis with exception of a single article (Frana, 2004) on the short-lived Gopher system.

The commercialization of the web browser and its rapid development during the so-called browser wars between Netscape and Microsoft during the late 1990s received some thoughtful attention at the time (Cusumano & Yoffie, 1998), particularly in the context of the government's antitrust action against Microsoft (1998-2001). The latter loomed large as an apparently epoch-defining event, as testified to by business journalist Ken Aluetta's choice of the title *World War 3.0* (Auletta, 2001), but slipped quickly from public awareness in the light of subsequent world events and the Bush administration's decision to impose only token penalties on Microsoft. My own (Haigh, 2008a) sets the commercialization of web browser, server, and email technology into a broader historical context, sketching connections between the shaping of Internet technologies in the academic environment and their unexpected commercial success. This appeared in the recent book *The Internet and American*

Business (Aspray & Ceruzzi, 2008). Authors, mostly historians of information technology, were charged with examining different aspects of the rapid embrace of the Internet by business. Chapters focus on topics from the growth of online pornography to the rise of online travel agents. Tackling the history of such recent events carries undeniable risks, and the book's exclusive focus on the United States has incurred criticism, but the volume is likely to provide a useful and sometimes provocative foundation for future work on these topics.

The .com businesses of the late 1990s inspired many dozens of hastily written books lauding their vision, the inexperience of their youthful founders, and their ability to raise and spend large quantities of venture capital. Some of these turned into cautionary tales of failure and excess even as they were being written. But volumes devoted short-lived to firms like CDNow and boo.com are not really contributions to the historical literature, and even enduring companies such as Amazon were profiled too hastily and too early in their history to provide much insight. The flavor of the age is preserved with charm, confusion, and hubris intact in (Lewis, 2000; R. H. Reid, 1997; Wolff, 1998). More cynical perspectives, from the immediate aftermath of the crash, can be found in (Cassidy, 2002). Meanwhile the success of Google has inspired several new journalistic histories of the search engine and portal industry (Battelle, 2005; Stross, 2008; Vise & Malseed, 2005) and my own analytical overview(Haigh, 2008b). We do not yet have much historical distance on this era, and are too bound up in supporting or critiquing ideas advanced at the time to begin to put it into context. However work is underway to analyze more systematically the success and failure of early Internet firms (Goldfarb, Kirsch, & Miller, 2007).

Information Technology in Use – Why Study Applications?

The most convincing claim that can be made for the importance of information technology history is the importance of information technology in modern society. Computer technologies have, admittedly, had less influence on the fabric of life in America than early twentieth- and late nineteenth-century innovations such as automobiles, electric light, domestic refrigerators, air conditioning, or telephones. If we compare 1960 to 2010 we see that Americans still live in cities, drive around, purchase preserved food from supermarkets, watch moving pictures on screens, and talk for business and pleasure over long distances. Historians are instinctively skeptical of any kind of deterministic reasoning about the "impact" of technology on society, and the history of technology tells us that it is more common for technologies to adjust themselves to fit existing social practices and institutions than the reverse. Indeed we have been told since the late 1940s that computer technology will unleash some kind of social revolution, evidence of which often seemed lacking. Yet information technology has already played an important role in reshaping many aspects of daily life, and new applications and modes of use are being invented all the time.

Much early work in the field followed a heroic model in explaining and celebrating particular technological accomplishments. David Alan Grier has called, without apparent irony, for the development of "The Great Machine Theory of History" (Grier, 2003). But studying information technology itself cannot tell us how or why it has been used to change the world, as Tom Misa pointed out in an argumentative survey of the existing literature (Misa, 2007). Neither will studying the hardware or software industries, however fascinating the stories we uncover. These constitute only a tiny part of the economy. We can only understand the importance of information technology to society by studying it in use.

The study of users and use (Oudshoorn & Pinch, 2003) has emerged over the past decade or two as a central concern within the history of technology and the allied field of science and technology studies. An earlier focus on machines, their inventors, and the companies that produced them has shifted appreciably towards the people who used them. Historians of technology have tended to treat use and consumption (Cowan, 1987) as interchangeable, looking at technologies adopted and used directly by individuals. A parallel movement in the business literature on innovation and technological change has explored the role of organizations as users of technology (Yates, 2006) and the part played by users in developing new applications of technology (Von Hippel, 2005).

The next three sections survey historical work on the use of information technology in science, administration, and embedded control systems. Literature on other application areas is sparse indeed. An enormous amount has been written about the use of computers in schools and universities, but I am aware of no significant historical work on the topic. Computer use in libraries was the subject of two special issues of IEEE Annals of the History of Computing (Graham & Rayward, 2002). Domestic computer use has been the topic of some interesting sociological and anthropological work, such as (Lally, 2002), but is yet to be explored from an historical perspective. Likewise a truly vast ethnographic and social scientific literature has grown up on use of the Internet and other online systems, for example (Turkle, 1995), but nobody has attempted to reconstruct the history of networks from the user perspective.

Applications in Science

The electronic computer was invented as a tool for scientific and engineering calculation. Although its main market shifted during the 1950s to business administration, computer technology went on to transform the practice of science in one discipline after another. Without computers it would be quite impossible to crunch the vast quantities of data captured in particle physics experiments, map genomes, or perform the statistical analysis expected in many fields of social science.

David Alan Grier’s highly readable recent book (Grier, 2006) looks at the human and institutional stories of large-scale mathematical calculation from the nineteenth century to the immediate aftermath of the Second World War. Its title, *When Computers Were Human* indicates that the term originally described a person who performed computations. Only later did people being to talk about “automatic computers” or “electronic computers.” The institutional history of scientific calculation in Britain has also been explored (Croarken, 1990), and an edited volume (Campbell-Kelly, Croarken, Flood, & Robson, 2003) looked specifically at the history of mathematical tables, the preparation of which motivated funding for several important projects including Babbage’s work and the ENIAC. Jen Light has explored (Light, 1999) gendered labor in the ENIAC project, showing that many programming tasks were carried out by women whose work was erased from media reports.

Electronic computers carried out calculations thousands of times faster than human computers with mechanical aids. A few institutional studies have been made of key users of computer technology for large scale calculation and simulation. These have focused on computer use in the national research labs of the Atomic Energy Commission (Seidel, 1998), particularly Los Alamos (Fitzpatrick, 1999; Mackenzie, 1991) and Argonne National Lab (Yood, 2005). The most ambitious book on early scientific computing is *Calculating a Natural World* (Akera, 2006), covering the ENIAC project and computing efforts at the National Bureau of Standards, MIT, IBM and the University of Michigan. Akera mixes historical genres such as biography, business history and the institutional history of science to chart the interdisciplinary "ecology of knowledge" (p.13-22) within which early computing practices sprang up.

Computers needed to be programmed, which turned out to be a lot harder and more time consuming than anyone had expected. Most of the scientific and technical calculations to which computers were applied involved calculating numerical approximations rather than manipulating algebraic symbols to achieve an exact solution. Existing mathematical methods, however, had been designed within the constraints of human mathematical labor. Harnessing the growing power of the digital computer thus demanded the creation of whole new families of mathematical methods and the development of new kinds of theory (particularly error analysis) and tacit knowledge. Numerical analysis emerged (Nash, 1990) as an important and growing field of research, and a new community (Cowell, 1984) developed from the 1960s on around the production of high quality mathematical software. However the history of mathematical software was addressed in a recent series of oral history interviews by the Society for Industrial and Applied Mathematics and is a fertile topic for future work by historians of computing.

Historians of science, unlike scientists, have been woefully slow to take computer technology seriously. There are a few exceptions to this general neglect. I Bernard Cohen, a Harvard historian of science and one of the discipline's American pioneers, took an interest in the work of Harvard computing pioneer Howard Aiken (I. B. Cohen, 1999), seeing him as a modern inventor on a par with historical subjects such as Ben Franklin. Peter Galison, a leading historian of physics, has drawn attention to the importance of studying the technologies of scientific instruments and their coevolution with theory and practice. His work (Galison, 1997) includes discussion of the computer as a device for data reduction and simulation, and of the evolving position of computer specialists within the social world of science. Historians of science have been drawn to the colorful and briefly fashionable world of cybernetics (Bowker, 1993; Heims, 1991), looking particularly (Kay, 2000) at connections between information theory, computing, and genetics. The computer's importance to weather forecasting and climate research has received some historical attention (Edwards, 2000; Harper, 2008), as has the introduction of computers into biological research (Hagen, 2001; November, 2006). More work will surely follow. As historians turn to the late twentieth- and early twenty-first centuries they will find it hard to tell the story of any discipline without covering the influence of technological change on its laboratory practice, publication patterns, methods of collaboration, or analytical habits.

Applications in Administrative Work and Business

From the mid-1950s onward the main market for computers has been in the world of business and government administration. The same was true of their most direct technological ancestors, punched card machines. Punched card machines were originally invented for use in tabulating the United States census. Their creator, Herman Hollerith, founded the business that became IBM. The origins of the punched card business were thus reasonably well covered in the voluminous literature on IBM and its international counterparts. Until recently, however, we knew much less about the capabilities of the machines themselves or the applications for which they were used.

Work by JoAnne Yates and Lars Heide has done a great deal to address these gaps. Heide (Heide, 2009) examines the development of punched card technology through the Second Word War in the US, France, Germany and Britain. Looking for evidence of the factors that shaped the development and adoption of the technology he explores not only the business history of punched card machine companies but also the role of key governmental applications, such as Social Security in the US and a national registry in France. Yates (Yates, 2005) focuses on a single American industry: life insurance. Using several detailed case studies she demonstrates the important role of user companies in influencing, and sometimes pioneering, the addition of new technological capabilities. Her work is also notable for its recognition of technological adoption as something that takes place by an entire industry, guided by trade associations and informal networks, rather than by isolated firms. She follows the story through to the 1960s, documenting the gradual transition from punched card machines to electronic computers.

In 1954 General Electric became the first American company to computerize an administrative job when it began to use a Univac computer to issue payroll checks to some of the workers at its Louisville, Kentucky appliance plant (Osborn, 1954). However, somewhat less predictably, it was not the world's first business to do so. This honor goes to Lyons, a British company best known for its nationwide chain of teashops. So keen were business systems experts within this company to apply the power of the computer to their administrative chores that they built their own computer, modeled on Cambridge University's EDSAC, rather than wait for one to be available commercially. It entered service in late 1951. This gave rise to LEO Computers, a computer hardware and systems implementation company which enjoyed reasonable commercial success into the 1960s. The quirkiness of this story has ensured it significant popular attention (Bird, 1994), most recently in a well told account (Ferry, 2003) that properly situates the story in the broader context of administrative systems work. The most detailed account of the LEO story was given by the participants themselves (Caminer, Aris, Hermon, & Land, 1996).

Yates's work on the insurance industry provides the only extended treatment of the use of information technology in a single American industry. Bernardo Batiz-Lazo and his colleagues have written a number of papers (Batiz-Lazo & Billings, 2007; Batiz-Lazo & Boyns, 2004; Batiz Lazo, 2009) about the co-evolution of information technology and business operations in the banking industry, which collectively provide similar insights for another corner of the financial world. Other English language studies of computer use elsewhere include an examination of computerization in three Dutch institutions (D. de Wit, 1994), of an early airline reservation system (McKenney, Copeland, & Mason, 1995), in the British Railway Clearing House (Campbell-Kelly, 1994), in the banking industry and in various corners of the British government (Agar, 2003). The latter is an ambitious and sprawling work, positing connections between the organization and culture of the civil service and the particular uses it made information technologies and techniques of administrative systematization. The early use of and development of systems for materials requirements processing (precursors to today's integrated enterprise software suites) has been explored in an article (Peeters, 2009) and dissertation (Kahl, 2007).

Until the 1970s there was no significant market for prepackaged application software (Haigh, 2002). Any company installing a computer also had to assemble a team of systems analysts and application programmers to create or extensively modify each of the programs it planned to run. This was true even of very common applications such as payroll, inventory management, or accounting. For this reason the history of administrative computer use is also, for its first few decades, largely congruent with the history of administrative application development. Each new computer installation was accompanied by a data processing department, home to teams of well paid specialists whose number and variety increased inexorably along with the department's budget. Data processing (Haigh, 2001a) evolved as a set of practices, a new institution whose place on the corporate organization chart remained in flux, and a cluster of new occupational identities. A careful overview of the history of system development practices, intertwining organizational and technological developments, is given in (Friedman & Cornford, 1989).

Very little has been published about the social history or labor practices of information technology, with the work of computer operators and data entry clerks shrouded in particular obscurity. A recent dissertation (Hicks, 2009) looks at data processing workers within the British government. Martin Campbell-Kelly produced a series of three very detailed technical studies of programming practices around the very first British computers, summarized in (Campbell-Kelly, 1982), but nothing has been attempted for the later period. I have presented (Haigh, 2001b) the genesis of the idea of the management information system as an episode in the social history of corporate America, driven by the aspirations of the self-proclaimed "systems men." The rhetoric surrounding computer programming in the 1960s has received some historical attention (Ensmenger, 2003) and the experience of system development work has been vividly captured in memoir (Ullman, 1997).

To call this coverage of administrative computing patchy would be to greatly exaggerate its comprehensiveness. A dearth of secondary accounts has not, however, been enough to deflect the boundless energies of James W. Cortada. A prolific author of works on the history and management of information technology in business, Cortada is also an IBM executive. His three volume opus *The Digital Hand* chronicles the use of computers in manufacturing, transport and retail industries (Cortada, 2003), service and communication industries (Cortada, 2006) and the public sector (Cortada, 2007). Each section examines the introduction of successive waves of computer technology with a focus on the applications and technologies most distinctively associated with the industry in question. These chapters will provide valuable starting points for future historians and Cortada's voluminous footnotes are an impressive resource.

Applications in Embedded and Control Systems

Historical attention has been focused primarily on computers that look like computers. The computer has had several paradigmatic forms over time (Atkinson, 1998). In the 1940s and early 1950s this meant ramshackle looking complexes of wires, switches and electronic components arranged in metal frames. In the late 1950s and 1960s it means complexes of smooth metal boxes, elegantly arranged with wires hidden under raised flooring and an array of printers, disk drives, and particularly the iconic banks of spinning tape drives. The minicomputer, which came into its stride in the late 1960s, was a smaller box with a generous selection of switches and flashing lights. And the personal computer, with which historians are just starting to get involved, tended to look like a typewriter or piece of consumer electronics but remained a self contained box coupled with a screen and a selection of other, smaller, peripheral boxes.

But since the 1970s most computers have not looked like this at all. The microprocessor, core of the personal computer, was originally invented for use in a pocket calculator (Aspray, 1997). It shrank the core capabilities of a programmable digital computer onto a single chip. Coupling it with a small amount of memory and control programs burned onto a ROM chip made it an affordable and flexible automatic control system for equipment of all kinds. By the 1980s these camouflaged computers, known as embedded systems, were standard equipment inside cars, microwave ovens, digital watches, washing machines, ATMs, home heating control boxes, video game consoles, and Video Cassette Recorders. Without them more recent consumer products such as the cellphone and iPod would have been impossible. Some luxury cars now contain more than a hundred microprocessors.

The microprocessor made embedded computer control systems cheap and tiny. But in fact they have a long history in applications with large budgets or specialized needs. Indeed the devices to be called computers were not free-standing boxes but the control mechanisms used to guide torpedoes, control antiaircraft guns and so on from the 1930s onward (D. A. Mindell, 2002). David Mindell's book *Between Human and Machine* explores the gradual development of automatic control technologies over the first half of the twentieth century. Subtly undermining the claims of cybernetics to have achieved a revolution during and just after the Second World War, he credits a variety specialized engineering communities with incremental advances based on local practices.

The single most important project for the development of computer technology was the development of the SAGE air defense network in the 1950s. This began as an effort at MIT to develop a high speed digital computer, Whirlwind. Whirlwind and SAGE pioneered a number of key technologies, among them real-time computer operation, networking, graphics, core memory, complex systems software, and light guns (a kind of precursor of the mouse). They have been profiled in two detailed technical histories (Redmond & Smith, 2000; Redmond & Smith, 1980) and given a lively portrait as artifacts of Cold War military thinking in *The Closed World* (Edwards, 1996). The latter is one of the few books on the history of information technology to win wide recognition among members of the science studies community.

The computers built for SAGE were the most powerful of their day and physically largest ever constructed (275 tons each). Other military applications required smaller, portable computers (P. Ceruzzi, 1989). Computers guided missiles (at first from the ground, later inside the missile itself) and were built into planes for navigation and weapons control. Applications such as the Minuteman I and II missiles drove fundamental advances in the use and packaging of electronics, creating a need for small, reliable and modularized components.

In the 1960s the space program played an important role in boosting the development of rugged, miniaturized computer systems including the Apollo guidance computer used in its command module and landing craft. In his book on this topic (D. Mindell, 2008), as in his earlier work, Mindell stresses the engineering of systems including both human and machine elements. NASA has a well developed program of high quality commissioned histories, meaning that many aspects of its technical and institutional history are well documented. Perhaps the most relevant is (Tomayko, 2000), a history of NASA's successful push to transfer computer control technologies to aircraft.

Programmable computers also found early application in industrial control (Stout & Williams, 1995). They were particularly well suited to continuous flow industries, such as oil and chemical processing. Although the automatic factory was potent concept in political debate and popular culture from the 1950s onward) little has so far been written on its history with the exception of David Noble's provocative *Forces of Production* (Noble, 1984). Noble, writing from a Marxist perspective heavily influenced by the work of 1970s labor theorist Harry Braverman, surveyed the development of automatic machine tools in the context of the Cold War. He argued that the ideological desire of business managers and computer researchers to replace skilled and potentially troublesome workers with machines had pushed the development of this technology in a dehumanising and inefficient direction. The book is undeniably a polemic, but Noble's determination to ground technical history in its broadest possible social context and illustrate the effect of technical choices on the experience of ordinary people reminds us of just how narrowly focused most other work in this area has been and of how useful the historical study of information technology might be in understanding the direction of society over recent decades.

Studies of more recent embedded systems are conspicuous by their absence. There have been a couple of studies of the cellphone but these have paid little attention to the status of handsets as special purpose computers. Historians of recorded music, film, and popular culture have yet to get to grips with the influence of computer-based media such as DVDs, MP3 files and IPods. Nobody has yet told the story of the computerization of cars, and even the pocket calculator (received in the 1970s as an icon of the microelectronic revolution to come) has failed to attract a scholarly history. However Greg Downey has recently looked at the evolution of television closed captioning (made possible by microcomputers and embedded chips) from the perspective of labor and political history (Downey, 2008).

Videogames have attracted a thriving industry of scholars from cultural studies, economics, and anthropology but, despite a respectable industry producing coffee table books and memoirs devoted to classic video games, historical research on this topic is only just beginning to appear. The most notable book to date is *Racing the Beam* (Montfort & Bogost, 2009), which draws on concepts from the field of Science and Technology Studies to explore the influence of technological choices made in the design of the seminal and charmingly primitive Atari VCS game console (released 1977) on the subsequent evolution of game design and programming practice in the home videogame industry that grew up around it.

Future of the History of Information Technology

The history of information technology has until recently been a rather obscure subfield falling mostly within the history of technology. Within the last few years it has become much more visible in history of technology journals and conferences and is beginning to assume greater prominence within business history and the history of science. But most work in the area continues to reflect the mindset and concerns of technical specialists rather than the concerns of academic historians. Its questions and methods are at best unconcerned with academic fashion and at worst antediluvian. Class, race, and gender emerged several decades ago as the central analytical categories in social history but rarely surface in historical discussion of information technologies. Neither have the “linguistic turn” of the 1970s or the “cultural turn” of the 1980s, inescapable in the humanities, been taken very often. Histories of information technology have rarely considered representative experiences, social changes, or the influence of information technologies on different kinds of work. To be blunt, outsiders from more mature historical subfields are likely to find the bulk of existing scholarship narrow, dry, obsessed with details, under conceptualized, and disconnected from broader intellectual currents.

This is already beginning to change, driven by the growing and changing importance of information technology in the world itself. Computers have, as discussed previously, become a kind of universal technology. They have (whether in recognizable forms or embedded within digital appliances) replaced many of the technologies formerly ubiquitous in everyday life. For the relatively small band of scholars who identify primarily as historians of computing or of information technology this poses challenges and opportunities. As the history of the early twenty first century is written nobody telling the story of any genre of popular music, any industry, any company, any scientific discipline, or any form of communication will be able to tell their story fully without paying some attention to information technology. And yet it is neither realistic nor desirable to imagine that fifty years hence most historians will call themselves historians of information technology. What does that mean for the history of information technology? Must it become the history of everything? If so who will write it and what can we do with it?

The obvious parallel is with the history of the book (which is, after all, an information technology in the literal sense). Historians, literary scholars, and other humanities researchers write about books and their authors all the time. Yet the book itself is often taken for granted. “History of the book” has emerged as an interdisciplinary field probing the materiality of culture. It cuts across established fields of studies and historical narratives to rediscover the evolution of book technology and its relationship to reading practices, publishing industries, and intellectual history.

Perhaps the history of information technology may one day win recognition as a similarly interdisciplinary endeavor, an intellectual space for people interested in the relationship between the internal characteristics of computer technology and its applications and interpretations in many different fields. Attention to information technology will likewise provide novel or subversive ways to reinterpret historical causality, upend assumptions about high and low cultures, and expose the role of technological change in unexpected places. With historical distance the cultural power and slippery appeal of ideas such as “information revolution” and “the digital” will make them attractive frames in which to understand much of the late twentieth-century. But the biggest challenge will be for those few historians, among whose number I count myself, who care deeply about information technology as technology, savoring arcane knowledge of Turing machines, network protocols, and long dead mainframes. It will not be enough to dive deep into the internals of these devices and tell their stories. We must resurface from our excursions holding insights packaged in such a way as to be useful and comprehensible to the many, many historians who will be studying the process by which one or another field of human endeavor was fundamentally restructured around the capabilities of these protean devices.

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