From Tool to Partner: The Evolution of Human-Computer Interaction

Synthesis Lectures on Human-Centered Informatics

Editor
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From Tool to Partner: The Evolution of Human-Computer Interaction

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Microsoft Research

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ABSTRACT

This is the first comprehensive history of human-computer interaction (HCI). Whether you are a user-experience professional or an academic researcher, whether you identify with computer science, human factors, information systems, information science, design, or communication, you can discover how your experiences fit into the expanding field of HCI. You can determine where to look for relevant information in other fields—and where you won't find it.

This book describes the different fields that have participated in improving our digital tools. It is organized chronologically, describing major developments across fields in each period. Computer use has changed radically, but many underlying forces are constant. Technology has changed rapidly, human nature very little. An irresistible force meets an immovable object. The exponential rate of technological change gives us little time to react before technology moves on. Patterns and trajectories described in this book provide your best chance to anticipate what could come next.

We have reached a turning point. Tools that we built for ourselves to use are increasingly influencing how we use them, in ways that are planned and sometimes unplanned. The book ends with issues worthy of consideration as we explore the new world that we and our digital partners are shaping.

KEYWORDS

human-computer interaction, human factors, information systems, information science, office automation, artificial intelligence, history, symbiosis, publication culture, Moore's law, hardware generations, graphical user interface

Contents

Preface

We have reason to celebrate. Half a century ago, inspirational accounts described how computers might someday enable people to accomplish amazing things. Computers at that time were huge, expensive, and could do very little. It took fifty years, but we did it! The early visions have been realized. There is always more to be done, and the next fifty years could be more exciting than the last, but we should recognize what we have collectively accomplished, how we did it, and what this can tell us about the next steps. This book describes what we accomplished, how we did it, and who "we" are. Knowing this should help us take our next steps.

As computers became available, people with different goals looked for ways to make these flexible tools useful: engineers and scientists, businesses and government agencies, hobbyists, librarians and information professionals, and eventually the general public. Different research and development communities formed, in human factors, management information systems, computer science, and library and information science. Most people who are engaged in understanding and improving human-computer interaction associate with one of these fields or with more recent arrivals such as design and communication studies, or they work outside these fields yet draw on findings and methods from them.

It requires an effort to grasp the relationships among these disciplines and discover what could be useful for you. Even the origins and span of your own field may be unclear. To understand what your field is, you must discover what it is not. A good strategy is to see how closely related fields differ. This book was written to help with that. Understanding the past can be the best preparation for a future, despite the surprises that inevitably come.

In the early 1980s, I attended computer-human interaction (CHI) and human factors meetings. I was introduced to the management information systems literature. I wondered why these disciplines did not interact more. Over time, other questions arose: Why didn't the relevant National Science Foundation and the U.S. Department of Defense Advanced Research Projects Agency (ARPA) program managers attend CHI? Why was some of our field's most-acclaimed research ignored by practitioners?

I found answers to these and other questions. By examining similarities and differences in human-computer interaction (HCI) as practiced in computer science, human factors, information systems, and information science, we gain a deeper appreciation of the activity around us. You may find where you could benefit from other fields—and also see where exploration is less promising. Readers in fields that more recently embraced HCI, such as design and communication, can position themselves.

In revising and extending material that I previously published in various handbook chapters, the *IEEE Annals of the History of Computing*, and other places, I realized that we are developing a new relationship with digital devices. It is not a uniform relationship—it appears here and there—but the trajectory is clear even if the benefits and costs are not. The tools that we shaped take the initiative more often than they did in the past, creating new opportunities and new challenges for the designers, developers, and researchers who shift their perspective to explore the possibilities.

Acknowledgments

This book was assembled with contributions from hundreds of people who shared recollections, information, and additional sources. Without the encouragement of Ron Baecker and Phil Barnard, I would not have persisted. Steve Poltrock and I examined much of this ground in courses that we taught. John King and Clayton Lewis were fonts of information and ideas.

My wife Gayna Williams has been a constant partner in exploring and interpreting technology use. She shaped the chapters on recent activity. Seeing my daughters Eleanor and Isobel encounter technology has brought into sharper focus the nature and evolution of our interaction with machines.

Dick Pew generously provided the opportunity to write a history handbook chapter. Don Norman and Brian Shackel patiently responded to questions over the years. Gerhard Fischer, Gary Olson, Mark Tarlton, Steve Poltrock, Glenn Kowack, and Ron Baecker provided insightful comments on drafts and improved the prose immeasurably. Producing a book is a group effort: Diane Cerra's patient guidance, Deb Gabriel's exhaustive editing, Ted Laux's professional indexing, and Susie Batford's wonderful cover illustration, undertaken to improve your experience, had that effect on mine.

I owe special thanks to Don Chaffin and Judy Olson for pointing out the relevance of Lillian Gilbreth and Grace Hopper; no doubt I overlooked people whose contributions deserved inclusion, but I am glad these two made it.

Of the fields covered, library and information science, with roots in the humanities, is home to the most-professional historians. Their welcome to an amateur was wonderful. Exchanges with William Aspray, author of elegant histories of computer science, and Colin Burke, one of the most dedicated scholars I know, washed away any weariness from hours of tracking down information. I hope tomorrow's chroniclers—perhaps you—will draw on this in writing future histories.

CHAPTER 1

Preamble: History in a Time of Rapid Change

It was 1963. Few computers existed. Joseph Carl Robnett Licklider, an MIT psychologist and engineer, was appointed director at the U.S. Department of Defense Advanced Research Projects Agency (ARPA). He wrote "Memorandum for Members and Affiliates of the Intergalactic Computer Network." The ARPANET, predecessor to the internet, soon followed. It was not Licklider's first sketch of the future. His 1960 article on human-computer "symbiosis" envisioned three stages in the relationship of humans and the mammoth new devices that had far less capability than a graphing calculator does today:

1. Human-computer interaction. Machines are tools, extensions of the arm and eye. Licklider outlined the requirements to make progress: better input and output techniques, better interaction languages. In a 1965 book, *Libraries of the Future*, he provided a more detailed blueprint.

2. Human-computer symbiosis. "It will involve very close coupling between the human and the electronic members of the partnership," which "will think as no human brain has ever thought and process data in a way not approached by the information-handling machines we know today."

3. Ultra-intelligent machines. Assured by leading researchers that machines of greater than human intelligence were coming, Licklider "conceded dominance in the distant future of cerebration to machines alone."

We spent decades in the first stage, in which interaction consisted of a human acting and a computer reacting. We loaded a deck of cards, typed a command, selected a menu item, or clicked on an icon; the computer responded and then awaited our next action.

Reaching the second stage took longer than expected. But without fanfare, the partnership arrived. We've met Licklider's stage 1 goals. It is not an equal partnership. Software does not have a mind, but it can perform tasks that we can't and embody understandings that are based on insights of its human designers and augmented by contextual information that it acquired in use. Now, my devices act on my behalf. Not always and not dramatically, but even as I sleep, they receive, filter, and prioritize information for me. Often I take the initiative; other times my device does, or it offers to. Computer capabilities complement those of a human partner. Digital agents have narrow scopes of

action, so their human partners must assess the broader context. Digital partners often have impressive computational skills and clumsy social skills. But these partners are not an alien species; at their best, they represent a distillation of what we have learned so far about technology and ourselves.

This transition profoundly alters the perspectives that will best serve researchers and developers, in ways that we have not yet assimilated. Understanding the paths in designing and understanding interaction that brought us to this point will enable us to identify effective new approaches and to identify practices that are outmoded, as well.

1.1 WHY STUDY THE HISTORY OF HUMAN-COMPUTER INTERACTION?

"What is a typewriter?" my six-year-old daughter asked me.
I hesitated. "Well, it's like a computer," I began.

A widely read 1983 paper advised the designers of a word processor to use an analogy that was familiar to everyone: a typewriter.[1] Already by 1990, a Danish student challenged this reading assignment, arguing "the typewriter is a species on its last legs." My daughters are now teenagers. For them and their friends, typewriters are extinct, as are other species that participated in interaction through the computing era: 80-column punch cards, paper and magnetic tape, line editors, 1920-character monochrome displays, 1-megabye diskettes, CDs, and even DVDs. Are the interaction issues posed by those devices relevant today? No.

In contrast, aspects of the *human* side of human-computer interaction (HCI) change slowly if at all. Much of what was learned about our perceptual, cognitive, social, and emotional processes when we interacted with older technologies applies to emerging technologies. Our reasons for retrieving and organizing information persist, even when the specific technologies that we use change.

This book focuses on interactions with extinct as well as living technologies. There are several reasons for understanding the field's history. Paradoxically, the rapid pace of technology change could strengthen some of them.

1. Several disciplines are engaged in HCI research and application, but few people are exposed to more than one. By seeing how each evolved, we can identify potential benefits of expanding our focus and obstacles to doing so.

2. Celebrating the accomplishments of past visionaries and innovators is part of building a community and inspiring future contributors, even when some past achievements require an effort to appreciate today.

[1] Carroll and Mack 1984.

3. Some visions and prototypes were quickly converted to widespread application, others took decades to influence use, and a few remain unrealized. By understanding the reasons for different outcomes, we can assess today's visions more realistically.

4. Crystal balls are notoriously unreliable, but anyone planning or managing a career in a rapidly changing field must consider the future. Our best chance to anticipate change is to find trajectories that extend from the past through the present. The future will not resemble the present, so it is worth trying to prepare for it.

This account does not emphasize engineering "firsts." It focuses on technologies and practices as they became widely used, as reflected in the spread of systems and applications. This was often paralleled by the formation of new research fields, changes in existing disciplines, and the creation and evolution of professional associations and publications. More a social history than a conceptual history, this survey identifies trends that you might download into your crystal ball. For those interested in deeper exploration of conceptual history, I have gathered some resources in a short appendix.[2]

Not all methodological and theoretical contributions are covered. Some work that strongly influenced me is not covered; nor is my most-cited work. A historical account is a perspective. It emphasizes some things and de-emphasizes or omits others. A history can be wrong in details, but it is never right in any final sense. Your questions and interests determine how useful a given perspective is to you.

A model for intellectual histories of HCI was established by Ron Baecker in the 1987 and 1995 editions of *Readings in Human-Computer Interaction* and was followed by that of Richard Pew (2003) in Jacko and Sears's *Human-Computer Interaction Handbook*. Brian Shackel (1997) summarized European contributions. Perlman et al. (1995) is a compendium of early HCI papers that first appeared in the human factors literature. HCI research in management information systems is covered by Banker and Kaufmann (2004) and Zhang et al. (2009). Rayward (1983; 1998) and Burke (1994; 2007) review the pre-digital history of information science. The incandescent surge of activity in the 1970s and 1980s has been addressed in a wave of popular books, many of them listed in Appendix B.

My contributions to HCI history began with a short 2004 encyclopedia entry and a 2005 article in *IEEE Annals of the History of Computing*. I expanded these into a series of handbook chapters and further explored historical issues in essays that I wrote and invited others to write for a column published in *ACM Interactions* from 2006 to 2013.[3]

Neither I nor most of the authors mentioned above are trained historians. Many of us lived through much of the computing era as participants and witnesses, yielding rich insights and ques-

[2] Examples of relevant engineering and conceptual history essays are Myers (1998) on graphical user interfaces and Blackwell (2006) on the use of metaphor in design.

[3] See http://www.jonathangrudin.com/wp-content/uploads/2016/12/Timelines.pdf.

tionable objectivity. This account draws on extensive literature and hundreds of formal interviews and informal discussions, but everyone who participated in past events has biases. Personal experiences can enliven an account by conveying human consequences of changes that otherwise appear abstract or distant and can indicate possible sources of bias. Some readers enjoy anecdotes; others find them irritating. I try to satisfy both groups by restricting personal examples to an appendix, akin to "deleted scenes" on a DVD.

I include links to freely accessed digital reproductions of some early works. When a good Wikipedia article or YouTube video will be found with obvious search engine query terms, I do not interrupt with a full reference; for example, "Three Mile Island nuclear power disaster," "1984 Macintosh Super Bowl video," or "Mundaneum." Similarly, when a sentence identifies the author and year of a contribution, I do not add a citation, but the work appears in the references.

1.2 DEFINITIONS: HCI, CHI, HF&E, IT, IS, LIS

HCI is often used narrowly to refer to work in one discipline. I define it broadly to cover major threads of research and development in four disciplines: human factors, information systems, computer science, and library and information science. Later I discuss how differences in the use of simple terms make it difficult to explore the literature. Here I explain my use of key disciplinary labels. computer-human interaction (CHI) is given a narrower focus than HCI; CHI is associated primarily with computer science, the Association for Computing Machinery Special Interest Group (ACM SIGCHI), and the latter's annual CHI conference. I use human factors and ergonomics interchangeably and refer to the discipline as HF&E. (Some writers define ergonomics more narrowly around hardware.) The Human Factors Society (HFS) became the Human Factors and Ergonomics Society (HFES) in 1992. Information systems (IS) refers to the discipline within schools of management or business that has also been labeled data processing (DP) and management information systems (MIS), and sometimes information technology (IT). Organizational information systems specialists are referred to here as IT professionals, or IT pros. The Association for Information Systems Special Interest Group on Human Computer Interaction (AIS SIGHCI) should be distinguished from SIGCHI. Library and information science (LIS) represents an old field with a new digital incarnation that includes important HCI research. With "IS" taken by information systems, I do not abbreviate information science, a discipline that often goes by simply "information." "Information schools" proliferated in recent years, sometimes replacing "library schools." A Glossary of these and other acronyms is provided.

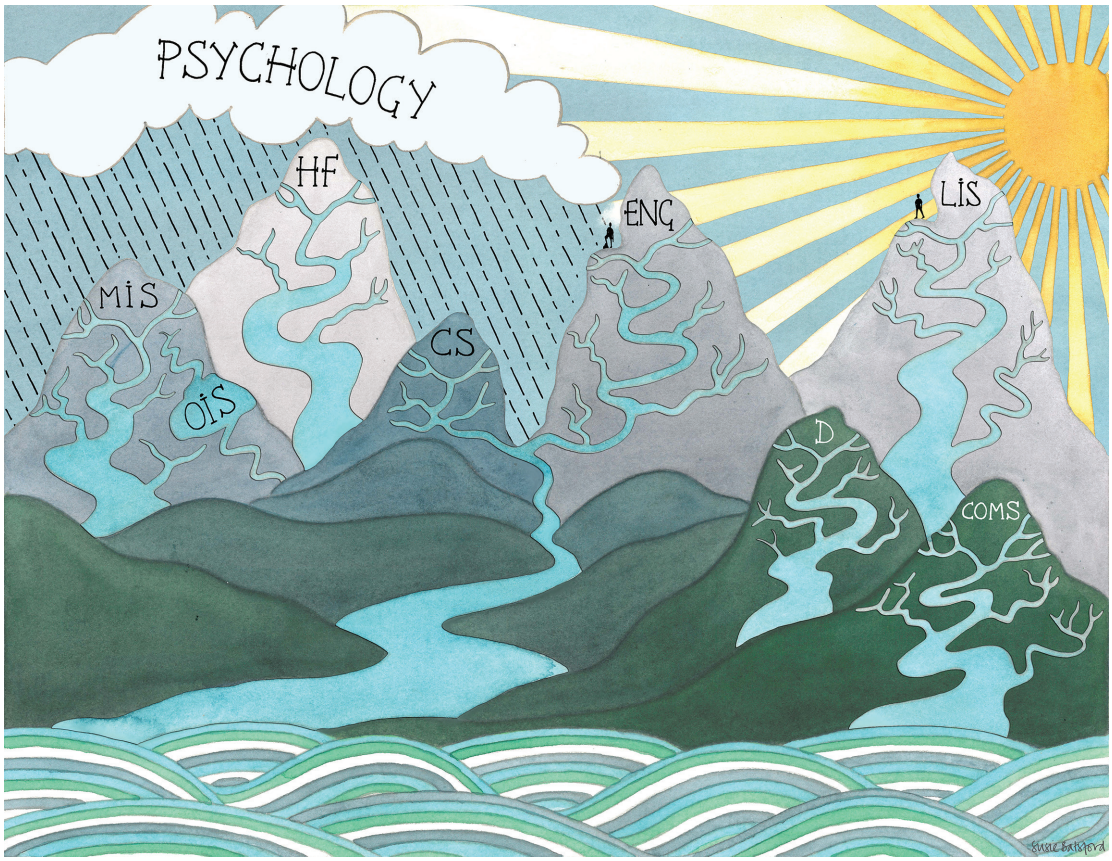
1.3 SHIFTING CONTEXT: MOORE'S LAW AND THE PASSAGE OF TIME

A challenge in interpreting past events is keeping in mind the radical change in what a typical computer was from one decade to the next. Conceptual development can be detached from hardware to some extent, but the evolving course of research and development cannot. We are familiar with Moore's law, but we do not reason well about supralinear or exponential growth. People often failed to anticipate how rapidly change would come, and then when it came, they did not credit the role played by the underlying technology. Looking back, we often fail to recall the magnitude of that change.

Moore's law specifies the number of transistors on an integrated circuit; this book considers the broader range of phenomena that exhibit exponential growth. Narrowly defined, Moore's law may be revoked, but the health of the technology industry is tied to ongoing hardware innovation and efficiency gains. Don't underestimate human ingenuity when so much is at stake. Future advances could come through novel materials, three-dimensional architectures, optical computing, more effective parallelism, increased software efficiency, or something unexpected. They will come.

With the arrival of small and specialized devices, the definition of "computer" blurred. I use "computer" and "digital technology" interchangeably. Much of the historical literature forgets to adjust prices to account for inflation. One dollar when the first commercial computers appeared is equivalent to ten dollars today. I converted prices, costs, and funding to U.S. dollars as of 2016. In a few excerpts, I translated archaic 20th-century English into modern 21st-century English by replacing "man" with "human."

As computer use expanded, it attracted the attention of new fields. Think of HCI as streams that started high on several peaks and gathered strength as they flowed to a world-encircling sea. A few engineers and information technologists looked at a lively stream and imagined where it might go. Human factors and management information systems tributaries started. Most streams were nourished by different schools of psychology. Cognitive and social psychologists who saw how to guide an increasingly powerful torrent merged with computer scientists interested in graphics and software engineering. It was not over. Declining digital storage and processing costs fed the library and information science stream and brought a surge of design activity. As millions of people became networked, the discipline of communication expanded into computer-mediated communication and social media. Other fields contributed rivulets. HCI became ubiquitous.



The following chapters fill out this account, organized into eight historical periods and two that reflect on patterns that emerged and identify areas to attend to as we move forward.

CHAPTER 2

Human-Tool Interaction and Information Processing at the Dawn of Computing

In the century prior to arrival of the first digital computers, new technologies gave rise to two fields of research that later contributed to HCI. One focused on making the human use of tools more efficient, the other focused in ways to represent and distribute information more effectively.

2.1 LILLIAN GILBRETH AND THE ORIGINS OF HUMAN FACTORS

Frederick Taylor employed technologies and methods developed in the late 19th century—photography, moving pictures, and statistical analysis—to improve work practices by reducing performance time. Time-and-motion studies were applied to assembly-line manufacturing and other manual tasks. Despite the uneasiness with "Taylorism" reflected in Charlie Chaplin's popular satire *Modern Times*, scientists and engineers continued applying this approach to boost efficiency and productivity.

Lillian Gilbreth and her husband Frank were the first engineers to add psychology to Taylor's "scientific management." Lillian Gilbreth's Ph.D. was the first degree awarded in industrial psychology. She studied and designed for efficiency and worker experience as a whole; some consider her the founder of modern human factors. She advised five U.S. presidents and was the first woman inducted into the National Academy of Engineering.

World War I and World War II gave rise to efforts to match people to jobs, to train them, and to design equipment that was more easily mastered. Engineering psychology was born in World War II after simple flaws in the design of aircraft controls and escape hatches led to plane losses and thousands of casualties.[4] Among the legacies of World War II were respect for the potential of computing, based on code-breaking successes, and an enduring interest in behavioral requirements for design.

During the war, aviation engineers, psychologists, and physicians formed the Aeromedical Engineering Association. After the war, the terms "human engineering," "human factors," and

[4] Controls are discussed in Roscoe, (1997); the consequences of ill-designed escape hatches are in Dyson's (1979) chilling account.

"ergonomics" came into use, the latter primarily in Europe. For more on this history, see Roscoe (1997), Meister (1999), and HFES (2010).

Early tool use, whether by assembly-line workers or pilots, was not discretionary. If training was necessary, people were trained. One research goal was to reduce training time, but more important was to increase the speed and reliability of skilled performance.

2.2 ORIGINS OF THE FOCUS ON INFORMATION

Science fiction author H. G. Wells campaigned for decades to improve society by improving information dissemination. In a 1905 non-fiction book he proposed a system based on a new technology: index cards!

> These index cards might conceivably be transparent and so contrived as to give a photographic copy promptly whenever it was needed, and they could have an attachment into which would slip a ticket bearing the name of the locality in which the individual was last reported. A little army of attendants would be at work on this index day and night… An incessant stream of information would come, of births, of deaths, of arrivals at inns, of applications to post-offices for letters, of tickets taken for long journeys, of criminal convictions, marriages, applications for public doles and the like. A filter of offices would sort the stream, and all day and all night for ever a swarm of clerks would go to and fro correcting this central register, and photographing copies of its entries for transmission to the subordinate local stations, in response to their inquiries…

Would such a human-powered "Web 2.0" be a tool for social control or public information access? The image evokes both the potential and the challenges of the information era that are taking shape now, a century later.

In the late 19th century, technologies and practices for compressing, distributing, and organizing information bloomed. Index cards, folders, and filing cabinets—models for icons on computer displays much later—were important inventions that influenced the management of information and organizations in the early 20th century.[5] Typewriters and carbon paper facilitated information dissemination, as did the mimeograph machine, patented by Thomas Edison. Hollerith punch cards and electromechanical tabulation, celebrated steps toward computing, were heavily used to process information in industry.

Photography was used to record information as well as behavior. For almost a century, microfilm was the most efficient way to compress, duplicate, and disseminate large amounts of information. Paul Otlet, Vannevar Bush, and other microfilm advocates played a major role in shaping the future of information technology.

[5] Yates, 1989.

As the cost of paper, printing, and transportation dropped in the late 19th and early 20th centuries, information dissemination and the profession of librarianship grew explosively. Library associations were formed. The Dewey Decimal and Library of Congress classification systems were developed. Thousands of relatively poorly funded public libraries sprang up to serve local demand in the United States. In Europe, government-funded libraries were established to serve scientists and other specialists in medicine and the humanities. This difference led to different approaches to technology development on either side of the Atlantic.

In the U.S., library management and the training of thousands of librarians took precedence over technology development and the needs of specialists. Public libraries adopted the simple but inflexible Dewey Decimal classification system. The pragmatic focus of libraries and emerging library schools meant that technology development was left to industry. Research into the indexing, cataloging, and retrieval of information and the physical objects containing it was variously referred to as bibliography, documentation, and documentalism.

In contrast, the well-funded European special libraries elicited sophisticated reader demands and pressure for libraries to share resources, which promoted interest in technology and information management. The Belgian Paul Otlet obtained Melvyn Dewey's permission to create an extended version of his classification system to support what we would today call hypertext links. Otlet agreed not to implement his Universal Decimal Classification (UDC) in English for a time, an early example of a legal constraint on technology development. Nevertheless, UDC is still in use in some places.

In 1926, the Carnegie Foundation dropped a bombshell by endowing the Graduate Library School (GLS) at the University of Chicago to focus solely on research. For two decades Chicago was the only university granting Ph.D.s in library studies. GLS positioned itself in the humanities and social sciences, with research into the history of publishing, typography, and other topics.[6] *An Introduction to Library Science* (Butler, 1933), the dominant library research textbook for forty years, was written at Chicago. *It did not mention information technology at all*. Library science was shaped by the prestigious GLS program until well into the computer era and human-tool interaction was not among its major concerns. Documentalists, researchers who did focus on technology, were concentrated in industry and government agencies.

Burke (2007) summarized the early history, with its emphasis on training librarians and other specialists:

> Most information professionals … were focusing on providing information to specialists as quickly as possible. The terms used by contemporary specialists appeared to be satisfactory for many indexing tasks and there seemed no need for systems based on comprehen-

[6] Buckland, 1998.

sive and intellectually pleasing classification schemes. The goal of creating tools useful to non-specialists was, at best, of secondary importance.

My account emphasizes the points at which computer technologies came into what might be called "non-specialist use." This early history of information management is significant, however, because the web and declining digital storage costs have made it evident that everyone will soon become their own information manager, just as we are all now telephone operators. But I am getting ahead of our story. This chapter concludes with accounts of two individuals who, in different ways, shaped the history of information research and development.

2.2.1 PAUL OTLET AND THE MUNDANEUM

Like his contemporary H. G. Wells, Otlet envisioned a vast network of information. But unlike Wells, Otlet and his collaborators built one. Otlet established a commercial research service around facts that he had been cataloging on index cards since the late 19th century. In 1919 the Belgian government financed the effort, which moved to a record center called the Mundaneum. By 1934, 15 million index cards and millions of images were organized and linked or cross-referenced using UDC. Curtailed by the Depression and damaged during World War II, the work was largely forgotten. It was not cited by developers of the metaphorically identical Xerox Notecards, an influential hypertext system of the 1980s.

Technological innovation continued in Europe with the development of mechanical systems of remarkable ingenuity. Features included the use of photoreceptors to detect light passing through holes in index cards positioned to represent different terms, enabling rapid retrieval of items on specific topics.[7] These innovations inspired the work of a well-known American scientist and research manager.

Vannevar Bush and Microfilm Machines

MIT professor Vannevar Bush was one of the most influential scientists in American history. He advised Presidents Franklin Roosevelt and Harry Truman, served as director of the Office of Scientific Research and Development, and was president of the Carnegie Institute.

Bush is remembered today for "As We May Think," his 1945 *Atlantic Monthly* essay. It described the memex, a hypothetical microfilm-based, electromechanical information-processing machine. The memex was to be a personal workstation that enabled a professional to quickly index and retrieve documents or pictures and create hypertext-like associations among them. The essay, excerpted below, inspired computer engineers and computer scientists who made major contributions to HCI in the 1960s and beyond.

[7] Buckland, 2009.

What's not well known is that Bush wrote the core of his essay in the early 1930s, after which, shrouded in secrecy, he spent two decades and unprecedented resources on the design and construction of several machines that comprised a subset of memex features. None were successful. The details are recounted in Colin Burke's comprehensive *Information and Secrecy: Vannevar Bush, Ultra, and the Other Memex*.

Microfilm—photographic miniaturization—had qualities that attracted Bush, as they had Otlet. Microfilm was light, could be easily transported, and was as easy to duplicate as paper records (Xerox photocopiers did not appear until 1959). The cost of handling film was brought down by technology created for the moving picture industry. Barcode-like patterns of small holes could be punched on a film and read very quickly by passing the film between light beams and photoreceptors. Microfilm was tremendously efficient as a storage medium. Memory based on relays or vacuum tubes would never be competitive, and magnetic memory, when it eventually arrived, was less versatile and far more expensive. It is easy today to overlook the compelling case that existed for basing information systems on microfilm.

Bush's machines failed because of overly ambitious compression and speed goals and patent disputes, but ultimately most critical was that Bush was unaware of decades of research on classification systems. American documentalists had been active, albeit not well funded. In 1937, the American Documentation Institute (ADI) was formed, a predecessor of the Association for Information Science and Technology (ASIS&T). Had he worked with them, Bush, an electrical engineer by training, could have avoided the fatal assumption that small sets of useful indexing terms would easily be defined and agreed upon. Metadata design was a research challenge then, and still is.

Bush described libraries and the public as potential users, but his machines cost far too much for that. He focused on the FBI and CIA as customers, as well as military uses of cryptography and information retrieval. Despite the classified nature of this work, through his academic and government positions, his writings, the vast resources he commandeered, and the scores of brilliant engineers he enlisted to work on microfilm projects, Bush exerted influence for two decades, well into the computer era.

Bush's vision emphasized both associative linking of information sources and discretionary use:

> Associative indexing, the basic idea of which is a provision whereby any item may be caused at will to select immediately and automatically another. This is the essential feature of the memex… Any item can be joined into numerous trails… New forms of encyclopedias will appear, ready made with a mesh of associative trails [which a user could extend] …
>
> The lawyer has at his touch the associated opinions and decisions of his whole experience and of the experience of friends and authorities. The patent attorney has on call

> the millions of issued patents, with familiar trails to every point of his client's interest. The physician, puzzled by a patient's reactions, strikes the trail established in studying an earlier similar case and runs rapidly through analogous case histories, with side references to the classics for the pertinent anatomy and histology. The chemist, struggling with the synthesis of an organic compound, has all the chemical literature before him in his laboratory, with trails following the analogies of compounds and side trails to their physical and chemical behavior.
>
> The historian, with a vast chronological account of a people, parallels it with a skip trail, which stops only on the salient items, and can follow at any time contemporary trails which lead him all over civilization at a particular epoch. There is a new profession of trail blazers, those who find delight in the task of establishing useful trails through the enormous mass of the common record.

Bush knew that the memex was unrealistic. None of his many projects included the "essential" associative linking. Nevertheless, his descriptions of discretionary hands-on use of powerful machines by professionals was inspirational. His vision was realized 50 years later, built on technologies undreamt of in the 1930s and 1940s. Bush did not initially support computer development—their slow, bulky, and expensive information storage was clearly inferior to microfilm.

Bearers of information. Wells, Otlet, and Bush focused on index cards and microfilm, but the input and output technologies that would dominate the first decades of computing were already present: paper tape and especially punch cards. Early computers held one program at a time, so each job required loading a program and any required data. The program/data distinction was present centuries earlier. Paper tape with punched holes was used to program mechanical looms in the 18th century and punch cards to store information in the mid-19th century. Charles Babbage proposed punched "number cards" for the control of a "difference engine," or calculating engine. Herman Hollerith, inspired by cards on which train conductors punched a set of features describing each passenger, devised punch cards that were used for the 1890 U.S. Census. By the 1930s, millions were being produced daily. Their most successful descendant was the 80-column "IBM card," used to input programs and data and onto which output could be punched.

A typical computer center from the 1950s through the mid-1980s had keypunches, into which blank cards were loaded for entering program instructions and data; a card reader, into which cards were loaded; the computer itself, with switches and buttons for inputting commands; and a teletype that produced continuous paper output with perforations to separate, or "burst," the pages. It could also have a computer-controlled card punch for outputting data and a drive for magnetic tape, a storage medium that like a hard drive only the computer read. There might be a card sorter, a visually arresting machine that sorted cards by shooting them along a track and dropping them into different bins based on the holes in a specified column. Paper tape with punched holes was

used into the 1970s. By the late 1980s, interactive terminals and disk drives had displaced much of this, with magnetic tape mainly used for backup.

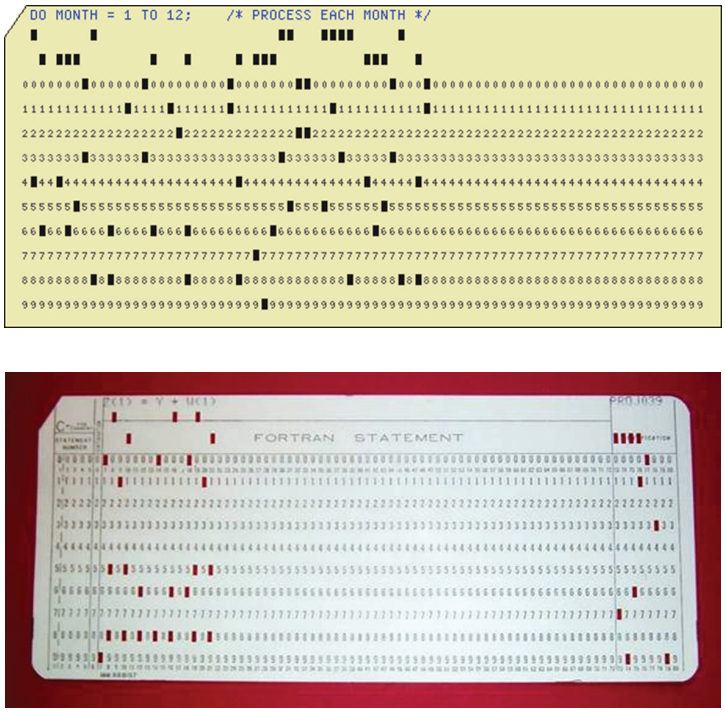


Figure 2.1: Two punch cards, long the most common medium for interacting with computers. Photo credits: Arnold Reinhold and Jeff Barr CC BY-SA 2.5.

CHAPTER 3

1945–1955: Managing Vacuum Tubes

World War II changed everything. Until then, most government research funding was managed by the U.S. Department of Agriculture. The war brought unprecedented investment in science and technology, culminating in the atomic bomb. This development showed that huge sums could be found for *academic or industrial research that addressed national goals*. Research expectations and strategies would never be the same.

Sophisticated electronic computation machines built before and during World War II were designed for specific purposes, such as solving equations or breaking codes. Each of the expensive cryptographic machines that helped win the war was designed to attack a specific encryption device. Whenever the enemy changed devices, a new machine was needed. This spurred interest in developing general-purpose computational devices. Wartime improvements in vacuum tubes and other technologies made this more feasible, and their deployment brought HCI into the foreground.

When engineers and mathematicians emerged from military and government laboratories and secret project rooms on university campuses, the public became aware of some breakthroughs. Development of ENIAC, arguably the first general-purpose computer, had begun in secret during the war; the "giant brain" was revealed publicly only when it was completed in 1946. Its first use was not publicized: calculations to support hydrogen bomb development. ENIAC stood 8–10 feet high, occupied about 1,800 square feet, and consumed as much energy as a small town. It provided far less computation and memory than you can slip into your pocket and run on a small battery today.

Memory was inordinately expensive. Even the largest computers of the time had little memory, so they were used for computation and not for symbolic representation or information processing. The HCI focus was to reduce operator burden, enabling a person to replace or reset vacuum tubes more quickly and load stored-program computers from tape rather than by manually attaching cables and setting switches. Such "knobs and dials" human factors improvements enabled one computer operator to accomplish work that had previously required a team.

Libraries installed simple microfilm readers to assist with information retrieval as publication of scholarly and popular material soared, but interest in technology was otherwise limited. The GLS orientation still dominated, focused on librarianship, social science, and historical research. Independently, the foundation of information science was coming into place, built on alliances that had been forged during the war among documentalists, electrical engineers, and mathematicians interested in communication and information management. These included Vannevar Bush and his collaborators Claude Shannon and Warren Weaver, co-authors in 1949 of a seminal work on information theory called communication theory at the time, and Ralph Shaw, a prominent Amer-

ican documentalist. The division between the two camps widened. Prior to the war, the technology-oriented ADI included librarians and support for systems that spanned humanities and sciences; during the war and thereafter, ADI focused on government and "big science."

3.1 THREE ROLES IN EARLY COMPUTING

Early computer projects employed people in three roles: management, programming, and operation. Managers, who often had backgrounds in science or engineering, specified the programs to be written; oversaw the design, development, and operation; and handled the output. Mathematically adept programmers decomposed tasks into components that a computer could manage. The first professional programming team comprised six women working on ENIAC. At the time, they were called "computers." They also debugged programs, sometimes by crawling into the giant machine to locate problems. In addition, a small army of operators was needed. Once written, a program could take days to load by setting switches, positioning dials, and connecting cables. Despite innovations that boosted reliability, such as operating vacuum tubes at lower power to increase life span and designing visible indicators of tube failure, ENIAC was often stopped so that failed vacuum tubes could be located and replaced. Vacuum tubes were reportedly wheeled around in shopping carts.

Eventually, each occupation—management and systems analysis, programming, and operation—became a major focus of HCI research, centered respectively in (management) information systems, computer science, and human factors. Significant HCI contributions from information science and other disciplines awaited greater processing power and sharply reduced prices for digital memory.

3.1.1 GRACE HOPPER: LIBERATING COMPUTER USERS

As computers became more reliable and capable, programming became a central activity. Computer languages, compilers, and constructs such as subroutines facilitated "programmer-computer interaction." Grace Hopper was a pioneer in all of these areas. She described her goal as freeing mathematicians to do mathematics.[8] It was echoed years later in the HCI goal of freeing users to do their work. In the early 1950s, mathematicians *were* the users! Hopper's work led to the development of COBOL, an English-like programming language for business systems that became and may still be the programming language in most widespread use in the world. At IBM, John Backus led the development of FORTRAN, also a highly successful English-like programming language, designed for scientific computing and released in 1957.

Just as HCI professionals often feel marginalized by software developers, Hopper's pioneering accomplishments in HCI were arguably undervalued by other computer scientists, although

[8] Hopper, 1952; Sammet, 1992.

she received recognition through the annual Grace Hopper Celebration of Women in Computing, initiated in 1994.

CHAPTER 4

1955–1965: Transistors, New Vistas

Early forecasts that the world would need only a few computers reflected the limitations of vacuum tubes. This changed when solid-state computers became available commercially in 1958. Computers were still used primarily for scientific and engineering tasks, but they were now reliable enough not to require a large staff to maintain one computer. As loading and running programs became more routine, operators with less engineering knowledge would be sufficient once more intuitive interfaces were developed. Although transistor-based computers were still very expensive and had limited capabilities, researchers could envision the previously unimaginable possibility of computers operated by people with no technical training.

The Soviet Union's launch of the Sputnik satellite in 1957 challenged the West to invest in science and technology. The development of lighter and more capable computers was an integral part of the well-funded program that put men on the moon 12 years later.

4.1 SUPPORTING OPERATORS: THE FIRST FORMAL HCI STUDIES

> "In the beginning, the computer was so costly that it had to be kept gainfully occupied for every second; people were almost slaves to feed it."
>
> —Brian Shackel (1997)

Almost all computer use in the late 1950s and early 1960s involved programs and data that were read in from cards, paper tape, or magnetic tape. A program then ran without interruption until it terminated, producing printed, punched, or tape output. This "batch processing" restricted human interaction to operating the hardware, programming, and using the output. Of these, the only job involving hands-on computer use was the least challenging and lowest paying, the computer operator. Programs were typically written on paper and keypunched onto cards or tape.

Computer operators loaded and unloaded cards and tapes, set switches, pushed buttons, read lights, loaded and burst printer paper, and put printouts into distribution bins. Operators interacted directly with the system via a teletype: typed commands interleaved with computer responses and status messages were printed on paper that scrolled up one line at a time. Eventually, printers yielded to "glass tty's" (glass teletypes), also called cathode ray tubes (CRTs), and visual display units or terminals (VDUs/VDTs). These displays also scrolled commands and computer responses one line at a time. The price of a monochrome terminal that could only display alphanumeric characters was $50,000 in today's dollars, a small fraction of the cost of the computer. A large computer might have