

A Moving Target—The Evolution of Human-Computer Interaction

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PREAMBLE: HISTORY IN A TIME OF RAPID OBSOLESCENCE

“What is a typewriter?” my six-year-old daughter asked.
I hesitated. “Well, it’s like a computer,” I began.

Why Study the History of Human-Computer Interaction?

A paper widely read 20 years ago concluded with the advice to design a word processor by analogy to something familiar to everyone: a typewriter. Even then, one of my Danish students questioned this reading assignment, noting that “the typewriter is a species on its last legs.” For most of the computing era, interaction involved 80-column punch cards, paper tape, line editors, 1920-character displays, 1-megabyte diskettes, and other extinct species. Are the interaction issues of those times relevant today? No.

Of course, aspects of the human side of human-computer interaction change more 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 our interaction with emerging technologies as well. Aspects of how we organize and retrieve information persist, even as the specific technologies that we use change. Other chapters of the handbook in which this essay appears lay out relevant knowledge of human psychology; how and when that was acquired is not my focus.

Nevertheless, there are reasons to understand the field’s history. The rapid pace of change could even strengthen 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 possible 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 are difficult to appreciate today.
3. Some visions and prototypes were quickly converted to widespread application, others took decades, and some 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 to the present. One thing is certain: The future will not resemble the present.

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 points to trends that you might download into your crystal balls.

A historical account is a perspective. It emphasizes some things while de-emphasizing or omitting others. A history can be wrong in details, but is never right in any final sense. Your questions and your interests will determine how useful a perspective is to you. This essay covers several disciplines, but software engineering, communication, design, and marketing receive less than attention than other accounts might provide.

A blueprint for intellectual histories of HCI was established by Ron Baecker in the opening chapters of the 1987 and 1995 editions of *Readings in Human-Computer Interaction*. It was followed in Richard Pew’s chapter in the 2003 version of this handbook. Further insights and references can be found in Brian Shackel’s (1997) account of European contributions, and specialized essays by Brad Myers (1998) on HCI engineering history and Alan Blackwell (2006) on the history of metaphor in design. Perlman et al. (1995) is a compendium of early HCI papers that appeared in the human factors literature. HCI research within 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; Burke (1998) provides a focused study of an early digital effort in this field.

A wave of popular books have addressed the history of personal computing (e.g., Hiltzik, 1999; Bardini, 2000; Hertzfeld, 2005; Markoff, 2005; Moggridge, 2007). This essay extends my contribution to the previous HCI handbook, drawing on new research and *Timelines* columns that *ACM Interactions* has published since March 2006.

Few of the aforementioned writers are trained historians. Many lived through much of the computing era as participants and witnesses, yielding rich insights and questionable objectivity. This account draws on extensive literature and hundreds of formal interviews and informal discussions, but everyone has biases. Personal experiences that illustrate points can enliven an account by conveying human consequences of changes that otherwise appear abstract or distant. Some readers enjoy anecdotes, others find them irritating. I try to satisfy both groups by including personal examples in a short appendix, akin to “deleted scenes” on a DVD.

Recent years have seen the appearance of high-quality, freely accessed digital reproductions of some early works. My references include links to several. The reproductions often do not preserve the original pagination, but quoted passages can be found with a search tool.

Definitions: HCI, CHI, HF&E, IT, IS, LIS

HCI is often used narrowly to refer to work in the discipline of an author or instructor. I define it very broadly to cover major threads of research in four disciplines: human factors, information systems, computer science, and library & information science. Later, I elaborate on differences in the use of simple terms that make the relevant literatures difficult to explore. Here I explain how several key disciplinary labels are used. CHI (computer-human Interaction) here has a narrower focus than HCI; CHI is associated mainly 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. IS (information systems) refers to the management discipline that has also been labeled data processing (DP) and management information systems (MIS). I follow common parlance in referring to organizational information systems specialists as IT professionals or IT pros. LIS (library and information science) represents an old field with a new digital incarnation that includes important HCI research. With IS taken, I do not abbreviate information science, a discipline that increasingly goes by simply 'information,' as in "Information School" or "School of Information."

Conventions: Moore's Law and Inflation

A challenge in interpreting past events and the literature is to keep in mind the radical differences in what a typical computer was from one decade to the next. We are familiar with Moore's law, but not with its many subtle effects. To some extent, conceptual development can be detached from hardware, but the evolving course of research and development cannot. Because we do not reason well about supralinear or exponential growth, we often failed to anticipate how rapidly change would come, and when it came we did not realize the role of the underlying technology. Moore's law specifies the number of transistors on an integrated circuit, but it is useful to consider the broader range of phenomena that exhibit exponential growth. Narrowly defined, Moore's law may soon be revoked, but broadly defined this is unlikely. The health of the technology industry is tied to ongoing hardware innovation. This provides the motivation and resources to continue, perhaps through novel materials and cooling techniques, three-dimensional architectures, optical computing, more effective parallelism, or other means. Do not underestimate human ingenuity when so much is at stake. There is also great opportunity for innovation and increased efficiency in software. Finally, there is a tendency in the literature to state costs in terms of dollars at the time of the events described, although one dollar when the first commercial computers appeared was equivalent to ten dollars today. I have converted prices, costs and grant funding to U.S. dollars as of 2012.

HUMAN-TOOL INTERACTION AND INFORMATION PROCESSING AT THE DAWN OF COMPUTING

In the century prior to the advent of the first digital computers, advances in technology gave rise to two fields of research that later contributed to human-computer interaction. One focused on making the human use of tools more efficient, the other on ways to represent and distribute information more effectively.

Origins of Human Factors

Frederick Taylor (1911) 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 working to boost efficiency and productivity using this approach.

Lillian Gilbreth (1914) and her husband Frank were the first engineers to combine psychology and scientific management. Lillian Gilbreth focused more holistically than Taylor on efficiency and worker experience; some consider her the founder of modern Human Factors. Her PhD was the first degree awarded in industrial psychology. She went on to advise five U.S. presidents and became the first woman inducted into the National Academy of Engineering.

World War I and World War II accelerated efforts to match people to jobs, train them, and design equipment that could be more easily mastered. Engineering psychology was born during World War II after simple flaws in the design

of aircraft controls (Roscoe, 1997) and escape hatches (Dyson, 1979) led to aircraft losses and thousands of casualties. Two legacies of World War II were respect for the potential of computing, based on its use in code-breaking, 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 '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 a more important goal was to increase the speed and reliability of skilled performance.

Origins of the Focus on Information

H. G. Wells, best known for writing science fiction, campaigned for decades to improve society through information dissemination. In 1905 he outlined a system that might be built using another new technology of the era: 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 the potential, and also the challenges, of the information era that is taking shape around us 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 (Yates, 1989). Typewriters and carbon paper facilitated information dissemination, as did the mimeograph machine, patented by Thomas Edison. Hollerith 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.

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 United States, 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 research into technology was in the province of industry. Research into indexing, cataloging, and information retrieval 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: It endowed the Graduate Library School (GLS) at the University of Chicago to focus solely on research. For two decades Chicago was the only university granting PhDs in library studies. GLS positioned itself in the humanities and social sciences, with research into the history of publishing, typography, and other topics (Buckland, 1998). *An Introduction to Library Science*, the dominant library research textbook for forty years, was written at Chicago (Butler, 1933). *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, p. 15) 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 comprehensive 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 section concludes with accounts of two individuals who, in different ways, shaped the history of information research and development.

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 (Buckland, 2009). 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. 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.

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 book *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 he set overly ambitious compression and speed goals, ignored patent ownership issues, and most relevant to our account, was unaware of what librarians and documentalists had learned through decades of work on classification systems. American documentalists were active although not well-funded. In 1937, the American Documentation Institute (ADI) was formed, predecessor of the American Society for Information Science and Technology (ASIST). Had he worked with them, Bush, an electrical engineer by training, might have avoided the fatal assumption that small sets of useful indexing terms could easily be defined and agreed upon. Metadata design is still a research challenge.

At times, Bush considered libraries and the public as potential users, but his machines cost far too much for library patrons to be plausible users. He envisioned the FBI as a customer and focused on military uses of cryptography and information retrieval; a final major project was for the CIA. 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 promoted his vision and 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, 1945.)

Bush knew that the MEMEX was not realistic. None of his many projects included designs for the "essential" associative linking. His inspirational account nicely describes the hands-on discretionary use of computers by professionals. But that would not arrive for 50 years, when it would be built on technologies then undreamt of. Bush did not support the early use of computers, which were slow, bulky, and expensive. Computers seemed clearly inferior to microfilm.

1945–1955: MANAGING VACUUM TUBES

World War II changed everything. Prior to the war, government funding of research was minimal and primarily managed by the Department of Agriculture. The unprecedented investment in science and technology during the war years revealed that huge sums could be found—for *academic or industrial research that addressed national goals*. Research expectations and strategies would never again 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 extremely expensive cryptographic machines that helped win the war was designed to attack a specific encryption device. A new one was needed whenever the enemy changed machines. These limitations spurred interest in general-purpose computational devices. War-time improvements in technologies such as vacuum tubes made them more feasible, and their deployment brought human-computer interaction 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, was begun in secret during the war but announced publicly as a 'giant brain' only when it was completed in 1946. (Its first use, for calculations supporting hydrogen bomb development, was not publicized.) Accounts of the dimensions of ENIAC vary, but it stood eight to ten feet high, occupied about 1800 square feet, and consumed as much energy as a small town. It provided far less computation and memory than can be acquired for a few dollars, slipped into a 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. A key HCI focus was to reduce operator burden; for example, by enabling them to replace or reset vacuum tubes more quickly and to load stored-program computers from tape rather than by manually attaching cables and setting switches. Through such 'knobs and dials' human factors improvements, one computer operator could 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. Beyond that, library and library school involvement with technology was limited, even as the foundation for information science came into place. The war had forged alliances among the documentalists, electrical engineers, and mathematicians interested in communication and information management. Vannevar Bush's collaborators in this effort included Claude Shannon and Warren Weaver, co-authors in 1949 of the seminal work on information theory (called communication theory at that time). Prominent American documentalist Ralph Shaw joined Bush's efforts. Library schools continued to focus on librarianship, social science, and historical research. The GLS orientation still dominated. The division widened: In the 1930s, the technology-oriented ADI included librarians and support for systems that spanned the humanities and sciences; with the arrival of the war and continuing after it, ADI's concerns became those of government and 'Big Science.'

Three Roles in Early Computing

Early computer projects employed people in three roles: managers, programmers, and operators. Managers oversaw design, development, and operation. They specified the programs to be written and distributed the output. Scientists and engineers wrote the programs, working with mathematically adept programmers who decomposed a task into

components that the computer could manage (for ENIAC, this was a team of six women). A small army of operators was needed. Once written, a program could take days to load by setting switches, dials, and cable connections. Despite innovations that boosted reliability, including operating vacuum tubes at lower power and building in visible indicators of their failure, ENIAC was often stopped to locate and replace failed tubes. Vacuum tubes were reportedly wheeled around in shopping carts.

Eventually, each occupation—computer operation, management and systems analysis, and programming—became a major focus of HCI research, centered respectively in Human Factors, Information Systems, and Computer Science. Computers and our interaction with them evolved, but our research spectrum still reflects aspects of this early division of labor.

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 these areas. She described her goal as freeing mathematicians to do mathematics (Hopper, 1952; see also Sammet, 1992). This is echoed in today's usability goal of freeing users to do their work. HCI professionals often argue that they are marginalized by software developers; in much the same way, Hopper's accomplishments have arguably been undervalued by theoretical computer scientists.

1955–1965: TRANSISTORS, NEW VISTAS

Early forecasts that the world would need few computers reflected the limitations of vacuum tubes. Solid-state computers, which became available commercially in 1958, changed this. Computers were still used primarily for scientific and engineering tasks, but they were reliable enough not to require a staff of computer engineers. The less computer-savvy operators who oversaw them needed better interfaces. Although computers were too expensive and limited to be widely used, the potential of transistor-based computing was evident. Some researchers envisioned possibilities that were previously unimaginable.

Another major force was the reaction to the Soviet Union's launch of the Sputnik satellite in October, 1957. This challenged to the West to invest in science and technology, and being seen as contributing to the response would tie a research program to the national interest, which World War II had revealed to be effective in attracting funding.

Supporting Operators: 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, p. 97)

Almost all computer use of this period involved programs and data that were read in from cards or tape. Programs then ran without interruption until they terminated, producing printed, punched, or tape output along the way. This 'batch processing' restricted human interaction to basic operation, programming, and use of the output. Of these, only computer operation, the least intellectually challenging and lowest-paying job, involved hands-on computer use.

Computer operators loaded and unloaded cards and magnetic or paper 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, they yielded to 'glass tty's' (glass teletypes), also called cathode ray tubes (CRTs) and visual display units/terminals (VDUs/VDTs). For many years, 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: expensive, but only a small fraction of the cost of the computer. A large computer might have one or more consoles. Programmers did not use the interactive consoles. Programs were typically written on paper and keypunched onto cards or tape.

Improving the design of buttons, switches, and displays was a natural extension of human factors. Experts in human factors and ergonomics authored the first HCI papers. In 1959, British researcher Brian Shackel published "Ergonomics for a Computer," followed in 1962 by "Ergonomics in the Design of a Large Digital Computer Console." These described console redesign for analog and digital computers called the EMIac and EMIdec 2400. Shackel (1997) described the latter as the largest computer of the time.

In the United States, American aviation psychologists created the Human Engineering Society in 1956. It focused on improving skilled performance through greater efficiency, fewer errors, and better training. The next year it adopted the more elegant title Human Factors Society and in 1958 it initiated the journal *Human Factors*. Sid Smith's (1963) "Man-Computer Information Transfer" marked the start of his long career in the human factors of computing.

Visions and Demonstrations

As transistors replaced vacuum tubes, a wave of imaginative writing, conceptual innovation, and prototype-building swept through the research community. Some of the language is dated, notably the use of male generics, but many of the key concepts still resonate today.

J.C.R. Licklider at BBN and ARPA. Licklider, a psychologist, played a dual role in the development of the field. He wrote influential essays and backed important research projects, as a manager at Bolt Beranek and Newman (BBN) from 1957 to 1962 and as director of the Information Processing Techniques Office (IPTO) of the Department of Defense Advanced Research Projects Agency (called ARPA and DARPA at different times) from 1962 to 1964.

BBN employed dozens of influential researchers on computer-related projects funded by the government, including John Seely Brown, Richard Pew, and many MIT faculty members, such as John McCarthy, Marvin Minsky, and Licklider himself. Funding from IPTO was crucial in creating computer science departments and establishing artificial intelligence as a discipline in the 1960s. It is best known for a Licklider project that created the forerunner of the Internet called the ARPANET, which was in use until 1985.

In 1960, Licklider outlined a vision of what he called *man-machine symbiosis*: “There are many man-machine systems. At present, however, there are no man-computer symbioses—answers are needed.” The computer was “a fast information-retrieval and data-processing machine” destined to play a larger role: “One of the main aims of man-computer symbiosis is to bring the computing machine effectively into the formulative parts of technical problems.” (pp. 4-5.)

This would require rapid, real-time interaction, which batch systems did not support. In 1962, Licklider and Wes Clark outlined the requirements of a system for “on-line man-computer communication.” They identified capabilities that they felt were ripe for development: time-sharing of a computer among many users; electronic input-output surfaces to display and communicate symbolic and pictorial information; interactive, real-time support for programming and information processing; large-scale information storage and retrieval systems; and facilitation of human cooperation. They foresaw that other desirable technologies, such as speech recognition and natural language understanding, would be very difficult to achieve.

In a 1963 memorandum that cleverly tied computing to the emerging post-Sputnik space program, Licklider addressed his colleagues as “the members and affiliates of the Intergalactic Computer Network” and identified many features of a future Internet (Licklider, 1963). His 1965 book *Libraries of the Future* expanded this vision. Licklider’s role in advancing computer science and HCI is detailed by Waldrop (2001).

John McCarthy, Christopher Strachey, Wesley Clark. McCarthy and Strachey worked out details of time-sharing, which made interactive computing possible (Fano & Corbato, 1966). Apart from a few researchers who had access to computers built with spare-no-expense military funding, computer use was too expensive to support exclusive individual access. Time-sharing allowed several (and later dozens of) simultaneous users to work at terminals. Languages were developed to facilitate the control and programming of time-sharing systems (e.g., JOSS in 1964).

Clark was instrumental in building the TX-0 and TX-2 at MIT’s Lincoln Laboratory to demonstrate time-sharing and other innovative concepts. These machines, which cost on the order of US\$10 million, helped establish the Boston area as a center for computer research. The TX-2 was the most powerful and capable computer in the world at the time. It was much less powerful than a smartphone is today. Clark and Ivan Sutherland discussed this era in a CHI’05 panel that is accessible online (Buxton, 2006).

Ivan Sutherland and Computer Graphics. Sutherland’s 1963 Ph.D. thesis may be the most influential document in the history of HCI. His Sketchpad system, built on the TX-2 to make computers “more approachable,” launched computer graphics, which would have a decisive impact on HCI twenty years later. A nice version restored by Alan Blackwell and Kerry Rodden is available (<http://www.cl.cam.ac.uk/TechReports/UCAM-CL-TR-574.pdf>).

Sutherland demonstrated iconic representations of software constraints, object-oriented programming concepts, and the copying, moving, and deleting of hierarchically organized objects. He explored novel interaction techniques, such as picture construction using a light pen. He facilitated visualization by separating the coordinate system used to define a picture from the one used to display it, and demonstrated animated graphics, noting the potential for digitally rendered cartoons 20 years before *Toy Story*. His frank descriptions enabled others to make rapid progress—when engineers found Sketchpad too limited for computer-assisted design (CAD), he called the trial a “big flop” and indicated why.

In 1964, with his Ph.D. behind him, Sutherland succeeded Licklider as the director of IPTO. Among those he funded was Douglas Engelbart at the Stanford Research Institute (SRI).

Douglas Engelbart: Augmenting Human Intellect. In 1962, Engelbart published “Augmenting Human Intellect: A Conceptual Framework.” Over the next several years he built systems that made astonishing strides toward realizing this vision. He also supported and inspired engineers and programmers who went on to make major independent contributions.

Echoing Bush and Licklider, Engelbart saw the potential for computers to become congenial tools that people

would choose to use interactively:

By 'augmenting human intellect' we mean increasing the capability of a man to approach a complex problem situation, to gain comprehension to suit his particular needs, and to derive solutions to problems... By 'complex situations' we include the professional problems of diplomats, executives, social scientists, life scientists, physical scientists, attorneys, designers... We refer to a way of life in an integrated domain where hunches, cut-and-try, intangibles, and the human 'feel for a situation' usefully co-exist with powerful concepts, streamlined terminology and notation, sophisticated methods, and high-powered electronic aids. (p. 1)

Engelbart used ARPA funding to rapidly develop and integrate an extraordinary set of prototype applications into his NLS system. In doing so, he conceptualized and implemented the foundations of word processing, invented or refined input devices including the mouse and the multikey control box, and made use of multi-display environments that integrated text, graphics, and video in windows. These unparalleled advances were demonstrated in a sensational 90-minute live event at the 1968 Fall Joint Computer Conference in San Francisco (<http://sloan.stanford.edu/MouseSite/1968Demo.html>). The focal point for interactive systems research in the United States was moving from the East Coast to the West Coast.

Engelbart, an engineer, supported human factors testing to improve efficiency and reduce errors in skilled use, focusing on effects of fatigue and stress. Use of Engelbart's systems required training. He felt that people should be willing to tackle a difficult interface if it delivered great power once mastered. Unfortunately, difficulty with initial use was a factor in Engelbart's loss of funding. His demonstration became something of a success disaster: DARPA was impressed and installed NLS, but found it too difficult (Bardini, 2000). Years later, the question "Is it more important to optimize for skilled use or initial use?" was widely debated and still occasionally surfaces in HCI discussions.

Ted Nelson's Vision of Interconnectedness. In 1960, Ted Nelson, a graduate student in sociology who coined the term *hypertext*, founded Project Xanadu. The goal was an easily-used computer network. In 1965, he published a paper titled "A File Structure for the Complex, the Changing and the Indeterminate." Nelson continued to write stirring calls for systems to democratize computing through a highly interconnected, extensible network of digital objects (e.g., Nelson, 1973). Xanadu was never fully realized. Nelson did not consider the early World Wide Web to be an adequate realization of his vision, but lightweight technologies such as weblogs, wikis, collaborative tagging, and search enable many of the activities he envisioned.

Later, Nelson (1996) foresaw intellectual property issues arising in digital domains and coined the term 'micropayment.' Although his solutions were again not fully implemented, they drew attention to the important issues.

From Documentalism to Information Science

The late 1950s saw the last major investments in microfilm and other pre-digital systems. The most ambitious were military and intelligence systems, including Vannevar Bush's final efforts (Burke, 1994). Documentalists began to see that declining memory costs would enable computation engines to become information processing machines. The conceptual evolution was relatively continuous, but at the institutional level, change could come swiftly. New professions—mathematicians and engineers—were engaged in technology development, new initiatives were launched that still bore few ties to contemporary librarianship or the humanities orientation of library schools. A new banner was needed.

Merriam Webster dates the term 'information science' to 1960. Conferences held at Georgia Institute of Technology in 1961 are credited with shifting the focus from information as a technology to information as an incipient science. In 1963, chemist-turned-documentalist Jason Farradane taught the first information science courses at City University, London. The profession of chemistry had long invested in organizing their literature systematically, and another chemist-turned-documentalist, Allen Kent, was at the center of a major information science initiative at the University of Pittsburgh (Aspray, 1999). In the early 1960s, Anthony Debons, a psychologist and friend of Licklider, organized a series of NATO-sponsored congresses at Pittsburgh. Guided by Douglas Engelbart, these meetings centered on people and on how technology could augment their activities. In 1964 the Graduate Library School at the University of Pittsburgh became the Graduate School of Library and Information Sciences, and Georgia Tech formed a "School of Information Science," initially with one full-time faculty member.

Conclusion: Visions, Demos, and Widespread Use

Progress in HCI can be understood in terms of inspiring visions, conceptual advances that enable aspects of the visions to be demonstrated in working prototypes, and the evolution of design and application. The engine, enabling visions to be realized and soon thereafter to be widely deployed, was the relentless hardware advance that produced devices that were millions of times more powerful than the much more expensive systems designed and used by the pioneers.

At the conceptual level, much of the basic foundation for today's graphical user interfaces was in place by 1965. However, at that time it required individual use of a US\$10 million custom-built machine. Pew (2003, p. 3) describes

the 1960 Digital Equipment Corporation (DEC) PDP-1 as a breakthrough, “truly a computer with which an individual could interact.” The PDP-1 came with a CRT display, keyboard, light pen, and paper tape reader. It cost about US\$1 million and had the capacity that a Radio Shack TRS 80 had twenty years later. It required considerable technical and programming support. Even the PDP-1 could only be used by a few fortunate computer-savvy researchers.

Licklider’s “man–computer symbiosis,” Engelbart’s “augmenting human intellect,” and Nelson’s “conceptual framework for man–machine everything” described a world that did not exist. It was a world in which attorneys, doctors, chemists, and designers chose to become hands-on users of computers. For some time to come, the reality would be that most hands-on users were computer operators engaged in routine, nondiscretionary tasks. As for the visions, 40 years later some of the capabilities are taken for granted, some are just being realized, and others remain elusive.

1965–1980: HCI PRIOR TO PERSONAL COMPUTING

Control Data Corporation launched the transistor-based 6000 series computers in 1964. In 1965, commercial computers based on integrated circuits arrived with the IBM System/360. These powerful systems, later called mainframes to distinguish them from minicomputers, firmly established computing in the business realm. Each of the three computing roles—operation, management, and programming—became a significant profession.

Operators still interacted directly with computers for routine maintenance and operation, and as timesharing became more widespread, hands-on use expanded to include data entry and other repetitive tasks. Managers and systems analysts oversaw hardware acquisition, software development, operation, and the use of output. Because they relied on printed output and reports they were called ‘computer users,’ although they did not interact directly with the computers.

Few programmers were direct users until late in this period. Most prepared flowcharts and wrote programs on paper forms. Key punch operators then punched the program instructions onto cards. These were sent to computer centers for computer operators to load and run. Printouts and other output were picked up later. Programmers might use computers directly when they could, but outside of research centers, the cost generally dictated this more efficient division of labor.

We are focusing on broad trends. Business computing took off in the mid-1960s, but the 1951 LEO I was probably the first commercial business computer. This interesting venture, which ended with the arrival of the mainframe, is detailed in Wikipedia (under ‘LEO computer’) and in the books and articles cited there.

Human Factors and Ergonomics Embrace Computer Operation

In 1970 at Loughborough University in England, Brian Shackel founded the Human Sciences and Advanced Technology (HUSAT) center, devoted to ergonomics research and emphasizing HCI. Sid Smith and other human factors engineers worked on input and output issues, such as the representation of information on displays (e.g., Smith, Farquhar & Thomas, 1965) and computer-generated speech (Smith & Goodwin, 1970). The Computer Systems Technical Group (CSTG) of the Human Factors Society was formed in 1972 and became the largest technical group in the society.

The general *Human Factors* journal was joined in 1969 by the computer-focused *International Journal of Man-Machine Studies (IJMMS)*. The first widely-read HCI book was James Martin’s 1973 *Design of Man–Computer Dialogues*. His comprehensive survey of interfaces for operation and data entry began with an arresting opening chapter that described a world in transition. Extrapolating from declining hardware prices, he wrote:

The terminal or console operator, instead of being a peripheral consideration, will become the tail that wags the whole dog. . . . The computer industry will be forced to become increasingly concerned with the usage of people, rather than with the computer’s intestines. (pp. 3–4)

In the mid-1970s, U.S. government agencies responsible for agriculture and social security initiated large-scale data processing system projects, described by Pew (2003). Although not successful, these efforts led to methodological innovations in the use of style guides, usability labs, prototyping, and task analysis.

In 1980, three significant HF&E books were published: two on VDT design (Cakir, Hart & Stewart, 1980; Grandjean & Vigliani, 1980) and one general guideline (Damodaran, Simpson & Wilson, 1980). Drafts of German work on VDT standards, made public in 1981, provided an economic incentive to design for human capabilities by threatening to ban noncompliant products. Later in the same year, a corresponding ANSI standards group for ‘office and text systems’ was formed.

Information Systems Addresses the Management of Computing

Companies acquired expensive business computers to address major organizational concerns. Even when the principal concern was simply to appear modern (Greenbaum, 1979), the desire to show benefits from a multi-million dollar investment could chain managers to a computer almost as tightly as the operator and data entry 'slaves.' In addition to being expected to make use of output, they might encounter resistance to system acceptance.

Beginning in 1967, the journal *Management Science* published a column titled "Information Systems in Management Science." Early definitions of IS included "an integrated man/machine system for providing information to support the operation, management, and decision-making functions in an organization" and "the effective design, delivery and use of information systems in organizations" (Davis, 1974, & Keen, 1980, quoted in Zhang, Nah & Preece, 2004, p. 147). In 1968, an MIS center and degree program was established at Minnesota. It initiated several influential research streams and in 1977 launched *MIS Quarterly*, the leading journal in the field. The MIS field juxtaposed a focus on specific tasks in organizational settings with demands for general theory and precise measurement, a challenging combination.

An historical survey by Banker and Kaufmann (2004) identifies HCI as one of five major IS research streams, dating it to Ackoff's (1967) paper describing challenges in handling computer-generated information. There was some research into hands-on operator issues such as data entry and error messages, but for a decade most HCI work in information systems dealt with the users of information, typically managers. Research included the design of printed reports, but the drive for theory led to a strong focus on cognitive styles: individual differences in how people (notably managers) perceive and process information. Articles on HCI were published in the human factors-oriented *IJMMS* as well as in management journals.

Sociotechnical approaches to system design (Mumford, 1971; 1976; Bjørn-Andersen & Hedberg, 1977) were developed in response to user difficulties and resistance. They involved educating representative workers about technological possibilities and involving them in design, in part to increase their acceptance of the resulting system. Late in this period, sophisticated views of the complex social and organizational dynamics around system adoption and use emerged (e.g., Kling, 1980; Markus, 1983).

Programming: Subject of Study, Source of Change

Even programmers who were not hands-on users were of course interacting with computers, and more than 1,000 research papers on variables affecting programming performance were published in the 1960s and 1970s (Baecker & Buxton, 1987, p. 147). Most were studies of programmer behavior in isolation, independent of organizational context. Influential reviews of this work included Gerald Weinberg's landmark *The Psychology of Computer Programming* in 1971, Ben Shneiderman's *Software Psychology: Human Factors in Computer and Information Systems* in 1980, and Beau Sheil's 1981 review of studies of programming notation (conditionals, control flow, data types), practices (flowcharting, indenting, variable naming, commenting), and tasks (learning, coding, debugging).

Software developers changed the field through invention. In 1970, Xerox Palo Alto Research Center (PARC) was founded to advance computer technology by developing new hardware, programming languages, and programming environments. It attracted researchers and system builders from the laboratories of Engelbart and Sutherland. In 1971, Allen Newell of Carnegie Mellon University proposed a project to PARC, which was launched three years later: "Central to the activities of computing—programming, debugging, etc.—are tasks that appear to be within the scope of this emerging theory [a psychology of cognitive behavior]" (Card & Moran, 1986, p. 183).

Like HUSAT, which was also launched in 1970, PARC had a broad charter. HUSAT focused on ergonomics, anchored in the tradition of nondiscretionary use, one component of which was the human factors of computing. PARC focused on computing, anchored in visions of discretionary use, one component of which was also the human factors of computing. Researchers at PARC, influenced by cognitive psychology, extended the primarily perceptual-motor focus of human factors to higher-level cognition, whereas HUSAT, influenced by sociotechnical design, extended human factors by considering organizational factors.

Computer Science: A New Discipline

Computer science departments in universities emerged in the mid-1960s. Some originated in engineering, others in applied mathematics. From engineering, computer graphics was a specialization of particular relevance to HCI. Applied mathematics was the background of many early researchers in artificial intelligence, which has interacted with HCI in complex ways in subsequent years.

The expensive early machines capable of interesting work were funded without consideration of cost by branches of the military. Technical success was the sole evaluation criterion (Norberg & O'Neill, 1996). Directed by Licklider, Sutherland, and their successors, ARPA played a major role. The need for heavy funding concentrated researchers in a few centers. These centers bore little resemblance to the batch and timeshared business computing environments of that era. User needs differed: The technically savvy hands-on users in research settings did not press for low-level interface enhancements.

The computer graphics and AI perspectives that arose in these centers differed from the perspectives of HCI researchers who focused on less expensive, more widely deployed systems. Computer graphics and AI required processing power—hardware advances meant declining cost for the same high level of computation. For HCI researchers, hardware advances meant greater computing capability at the same low price. Only later would this difference diminish, when widely-available machines could support graphical interfaces and some AI programs. Despite this gap, between 1965 and 1980 some computer science researchers focused on interaction, which is not surprising given the role of interaction in the early visions.

Computer Graphics: Realism and Interaction. In 1968 Sutherland joined David Evans to establish an influential computer graphics laboratory at the University of Utah. The Utah Computer Science department was founded in 1965, part of computer science's initial move into academic prominence. Utah contributed to the western migration as graduates of the laboratory, including Alan Kay and William Newman (and later Jim Blinn and Jim Clark), went to California. Most graphics systems at the time were built on the DEC PDP-1 and PDP-7. These expensive machines—the list price of a high-resolution display alone was equivalent to more than US\$100,000 in today's dollars—were in principle capable of multitasking, but in practice most graphics programs required all of a processor's cycles.

In 1973, the Xerox Alto arrived, a powerful step toward realizing Alan Kay's vision of computation as a medium for personal computing (Kay and Goldberg, 1977). The Alto was too expensive to be widely used—it was never widely marketed—and not powerful enough to support high-end graphics research, but it did support graphical interfaces of the kind Engelbart had prototyped. In doing so, the Alto signaled the approach of inexpensive, interactive, personal machines capable of supporting graphics. Computer graphics researchers had to decide whether to focus on high-end graphics or on more primitive features that would soon run on widely affordable machines.

William Newman, co-author in 1973 of the influential *Principles of Interactive Computer Graphics*, described the shift in a personal communication: "Everything changed—the Computer Graphics community got interested in realism, I remained interested in interaction, and I eventually found myself doing HCI." He was not alone. Other graphics researchers whose focus shifted to broader interaction issues included Ron Baecker and Jim Foley. Foley and Wallace (1974, p. 462) identified requirements for designing "interactive graphics systems whose aim is good symbiosis between man and machine." The shift was gradual: Eighteen papers in the first SIGGRAPH conference, in 1974, had the words "interactive" or "interaction" in their titles. A decade later, there would be none.

At Xerox, Larry Tesler and Tim Mott recognized that the Alto could support a graphical interface accessible to untrained people. The latter point had not been important given the prior focus on trained, expert performance. By early 1974 Tesler and Mott had developed the Gypsy text editor. Gypsy and Xerox's Bravo editor developed by Charles Simonyi preceded and influenced Microsoft Word (Hiltzik, 1999).

The focus on interaction was highlighted in 1976 when SIGGRAPH sponsored a two-day workshop in Pittsburgh titled "User Oriented Design of Interactive Graphics Systems." Participants who were later active in CHI included Jim Foley, William Newman, Ron Baecker, John Bennett, Phyllis Reisner, and Tom Moran. J.C.R. Licklider and Nicholas Negroponte presented vision papers. The conference was managed by the chair of Pittsburgh's computer science department. One participant was Anthony Debons, Licklider's friend who had helped build Pittsburgh's world-renowned information science program. UODIGS'76 arguably marked the end of a visionary period, embodying an idea whose time had not quite yet come. Licklider saw it clearly:

Interactive computer graphics appears likely to be one of the main forces that will bring computers directly into the lives of very large numbers of people during the next two or three decades. Truly user-oriented graphics of sufficient power to be useful to large numbers of people has not been widely affordable, but it will soon become so, and, when it does, the appropriateness and quality of the products offered will to a large extent determine the future of computers as intellectual aids and partners of people. (Licklider, 1976, p. 89.)

UODIGS was not repeated. Despite the stature of the participants, the 150-page proceedings were not cited. Not until 1981 was another "user oriented design" conference held, after which such conferences were held every year. Application of graphics was not quite at hand; most HCI research remained focused on interaction driven by commands, forms, and full-page menus.

Artificial Intelligence: Winter Follows Summer. In the late 1960s and early 1970s, AI burst onto the scene, promising to transform HCI. It did not go as planned. Logically, AI and HCI are closely related. What are intelligent machines for if not to interact with people? AI research has influenced HCI: Speech recognition and natural language are perennial HCI topics; expert, knowledge-based, adaptive and mixed-initiative systems have been tried, as have applications of production systems, neural networks, and fuzzy logic. Today, human-robot interaction and machine learning are attracting attention.

Although some AI features make it into systems and applications, frequent predictions that powerful machines would soon bring major AI technologies into wide use, and thus become a major focus of HCI research, were not borne out. AI did not come into focus in HCI, and AI researchers showed limited interest in HCI.

To piece this together requires a brief review of early AI history. The term *artificial intelligence* first appeared in a 1955 call by John McCarthy for a meeting on machine intelligence that was held in Dartmouth. In 1956, Alan Turing's prescient essay, "Computing Machinery and Intelligence," attracted attention when it was reprinted in *The World of*

Mathematics. (It was first published in 1950, as were Claude Shannon's "Programming a Computer for Playing Chess" and Isaac Asimov's *I, Robot*, which explored his three laws of robotics.) Newell and Simon (1956) outlined a logic theory machine and then focused on developing a general problem solver. McCarthy invented the LISP programming language in 1958 (McCarthy, 1960).

Many AI pioneers were trained in mathematics and logic, where almost everything is derived from a few axioms and a small set of rules. Mathematical ability is considered a high form of intelligence, even by non-mathematicians. AI researchers anticipated that machines that operate logically and tirelessly would make profound advances—by applying a small set of rules to a limited number of objects. Early AI focused on theorem-proving, games, and problems with a strong logical focus, such as chess and go. McCarthy (1988), who espoused predicate calculus as a foundation for AI, summed it up as follows:

As suggested by the term 'artificial intelligence,' we weren't considering human behavior except as a clue to possible effective ways of doing tasks. The only participants who studied human behavior were Newell and Simon. (The goal) was to get away from studying human behavior and consider the computer as a tool for solving certain classes of problems. Thus, AI was created as a branch of computer science and not as a branch of psychology.

Unfortunately, by ignoring psychology, mathematicians overlooked the complexity and inconsistency that mark human beings and our social constructs. Underestimating the complexity of intelligence, they overestimated the prospects for creating it artificially. Hyperbolic predictions and AI have been close companions. In the summer of 1949, the British logician and code-breaker Alan Turing wrote in the *London Times*:

I do not see why [the computer] should not enter any one of the fields normally covered by the human intellect, and eventually compete on equal terms. I do not think you can even draw the line about sonnets, though the comparison is perhaps a little bit unfair because a sonnet written by a machine will be better appreciated by another machine.

Optimistic forecasts by the 1956 Dartmouth workshop participants attracted considerable attention. When they collided with reality, a pattern was established that was to play out repeatedly. Hans Moravec (1998) wrote:

In the 1950s, the pioneers of AI viewed computers as locomotives of thought, which might outperform humans in higher mental work as prodigiously as they outperformed them in arithmetic, if they were harnessed to the right programs... By 1960 the unspectacular performance of the first reasoning and translation programs had taken the bloom off the rose.

A significant part of the pattern is that HCI thrives on resources that are freed when interest in AI declines. In 1960, with the bloom off the AI rose, the managers of MIT's Lincoln Laboratory looked for new uses for their massive government-funded TX-0 and TX-2 computers. Ivan Sutherland's Sketchpad and early computer graphics were a result.

The response to Sputnik reversed the downturn in AI prospects. J.C.R. Licklider, as director of ARPA's Information Processing Techniques Office from 1962 to 1964, provided extensive support for computer science in general and AI in particular. MIT's Project Mac, founded in 1963 by Marvin Minsky and others, initially received US\$13M per year, rising to \$24M in 1969. ARPA sponsored the AI Laboratory at SRI, AI research at CMU, and Nicholas Negroponte's Machine Architecture Group at MIT. A dramatic early achievement, SRI's Shakey the Robot, was featured in articles in *Life* (Darrach, 1970) and *National Geographic* (White, 1970). Given a simple but non-trivial task, Shakey could apparently go to the desired location, scan and reason about the surroundings, and move objects as needed to accomplish the goal (for Shakey at work, see <http://www.ai.sri.com/shakey/>).

In 1970, Negroponte outlined a case for machine intelligence: "Why ask a machine to learn, to understand, to associate courses with goals, to be self-improving, to be ethical—in short, to be intelligent?" He noted common reservations: "People generally distrust the concept of machines that approach (and thus why not pass?) our own human intelligence," and identified a key problem: "Any design procedure, set of rules, or truism is tenuous, if not subversive, when used out of context or regardless of context." This insight, that it is risky to apply algorithms without understanding the situation at hand, led Negroponte to a false inference: "*It follows that a mechanism must recognize and understand the context before carrying out an operation.*" (p. 1, my italics.)

A perfectly reasonable alternative is that the mechanism is guided by humans who understand the context: Licklider's human-machine symbiosis. Overlooking this, Negroponte built a case for an ambitious research program:

Therefore, a machine must be able to discern changes in meaning brought about by changes in context, hence, be intelligent. And to do this, it must have a sophisticated set of sensors, effectors, and processors to view the real world directly and indirectly... A paradigm for fruitful conversations must be machines that can speak and respond to a natural language... But, the *tete-à-tete* (sic) must be even more direct and fluid; it is gestures, smiles, and frowns that turn a conversation into a dialogue... Hand-waving often carries as much meaning as text. Manner carries cultural information: the Arabs use their noses, the Japanese nod their heads...

Imagine a machine that can follow your design methodology, and at the same time discern and assimilate your conversational idiosyncrasies. This same machine, after observing your behavior, could build a predictive model of your conversational performance. Such a machine could then reinforce the dialogue by using the predictive model to respond to you in a manner that is in rhythm with your personal behavior and conversational idiosyncrasies... The dialogue would be so intimate—even exclusive—that only mutu-

al persuasion and compromise would bring about ideas, ideas unrealizable by either conversant alone. No doubt, in such a symbiosis it would not be solely the human designer who would decide when the machine is relevant. (pp. 1-13.)

The same year, Negroponte's MIT colleague Minsky went further, as reported in *Life*:

In from three to eight years we will have a machine with the general intelligence of an average human being. I mean a machine that will be able to read Shakespeare, grease a car, play office politics, tell a joke, and have a fight. At that point, the machine will begin to educate itself with fantastic speed. In a few months, it will be at genius level and a few months after that its powers will be incalculable. (Darrach, 1970, p. 60.)

Other AI researchers told Darrach that Minsky's timetable was ambitious:

Give us 15 years' was a common remark—but all agreed that there would be such a machine and that it would precipitate the third Industrial Revolution, wipe out war and poverty and roll up centuries of growth in science, education and the arts.

Such predictions were common. In 1960, Nobel laureate and AI pioneer Herb Simon had written, "Machines will be capable, within twenty years, of doing any work that a man can do." (p. 38). Five years later, I. J. Good, an Oxford mathematician, wrote, "the survival of man depends on the early construction of an ultra-intelligent machine" that "could design even better machines; there would then unquestionably be an 'intelligence explosion,' and the intelligence of man would be left far behind" (pp. 31-33).

The Darrach article ended by quoting Ross Quillian:

I hope that man and these ultimate machines will be able to collaborate without conflict. But if they can't, we may be forced to choose sides. And if it comes to choice, I know what mine will be. My loyalties go to intelligent life, no matter in what medium it may arise. (p. 68).

It is important to understand the anxieties of the time, as well as the consequences of such claims. The world had barely avoided a devastating thermonuclear war during the Cuban missile crisis of 1962. Leaders seemed powerless to defuse the Cold War. Responding to a sense of urgency, ARPA initiated major programs in speech recognition and natural language understanding in 1971.

Ironically, central to funding this research was a psychologist not wholly convinced by the vision. Citing a 1960 Air Force study that predicted that intelligent machines might take 20 years to arrive, J.C.R. Licklider (1960) noted that in this interval HCI would be useful: "That would leave, say, five years to develop man-computer symbiosis and 15 years to use it. The 15 may be 10 or 500, but those years should be intellectually the most creative and exciting in the history of mankind." Ten to five hundred years represents breathtaking uncertainty. Recipients of Licklider's funding were on the optimistic end of this spectrum.

Five years later, disappointed with the progress, ARPA discontinued speech and language support—for a while. In Europe, a similar story unfolded. Through the 1960s, AI research expanded in Great Britain. A principal proponent was Turing's former colleague Donald Michie. Then in 1973, the Lighthill report, commissioned by the Science and Engineering Research Council, reached generally negative conclusions about AI's prospects for scaling up to address real-world problems. Almost all government funding was cut off.

The next decade has been called an AI winter, a recurring season in which research funding is withheld due to disillusionment over unfulfilled promises. The bloom was again off the rose, but it would prove to be a hardy perennial (Grudin, 2009).

Library Schools Embrace Information Science

Work on information science and "human information behavior" that was initiated in the 1960s and 1970s focused on scholarship and application in science and engineering (Fidel, 2011). The response to Sputnik proved that 'big science' research was alive and well following WW II. Aligning their work with national priorities became a priority for many researchers.

The terms 'information science,' 'information technology,' and 'information explosion' came into use. The Pittsburgh and Georgia Tech programs flourished. Pittsburgh created the first information science Ph.D. program in the United States in 1970, identifying humans "as the central factor in the development of an understanding of information phenomena" (Aspray, 1999, p. 12). The program balanced behavioral sciences (psychology, linguistics, communication) and technical grounding (automata theory, computer science). In 1973, Pittsburgh established the first information science department. Its program developed a strong international reputation. Slowly, the emphasis shifted from behavior to technology. On being awarded a major NSF center grant in 1966, the Georgia Tech school expanded. In 1970 it became a Ph.D.-granting school, rechristened Information and Computer Science.

In 1968, the American Documentation Institute became the American Society for Information Science, and two years later the journal *American Documentation* became *Journal of the American Society for Information Science*. In 1978 the ACM Special Interest Group on Information Retrieval (SIGIR) was formed and launched the annual "Information Storage and Retrieval" conference (since 1982, "Information Retrieval"), modeled on a 1971 conference. In 1984, the American Library Association belatedly embraced the i-word by creating the Association for Library and

Information Science Education (ALISE), which convened an annual research conference.

By 1980, schools at over a dozen universities had added the word 'information' to their titles. Many were library school transitions. Delivery on the promise of transformative information technology lagged, however. For example, from 1965 to 1972 the Ford and Carnegie Foundations, NSF, DARPA, and the American Newspaper Publishers Association invested over US\$30 million in MIT's Project Intrex (Burke, 1998). The largest non-military information research project of its time, Intrex was to be the library of the future. Online catalogs were to include up to 50 index fields per item, accessible on CRT displays, with full text of books and articles converted to microfilm and read via television displays. None of this proved feasible.

Terminal-based computing costs declined. The ARPANET debuted in 1969, and supported email in 1971 and file-sharing in 1973. This spurred visions of a 'network society' of the future (Hiltz & Turoff, 1978). As an aside, the technological optimism of AI and networking proponents of this era lacks the psychological insight and nuance of E.M. Forster, who in 1909 anticipated both developments in his remarkable story *The Machine Stops*.

1980–1985: DISCRETIONARY USE COMES INTO FOCUS

In 1980, HF&E and IS were focused on the down-to-earth business of making efficient use of expensive mainframes. The start of a major shift went almost unnoticed. Less expensive but highly capable minicomputers based on LSI technology were making inroads into the mainframe market. At the low end, home computers gained traction. Students and hobbyists were drawn to these minis and micros, creating a population of hands-on discretionary users. There were experimental trials of online library catalogs and electronic journals.

Then, between 1981 and 1984, a flood of innovative and powerful computers were released: Xerox Star, IBM PC, Apple Lisa, Lisp machines from Symbolics and Lisp Machines, Inc. (LMI), workstations from Sun Microsystems and Silicon Graphics, and the Apple Macintosh. On January 1, 1984, AT&T's breakup into competing companies took effect. AT&T had more employees and more customers than any other U.S. company. It was a monopoly: Neither its customers nor its employees had discretion in technology use. AT&T and its Bell Laboratories research division had employed human factors to improve training and operational efficiency. Suddenly freed from a ban on entering the computer business, AT&T launched the ill-fated Unix PC in 1985. Customers of AT&T and the new regional operating companies now had choices, and the HCI focus of the telecommunications companies broadened accordingly (Israelski & Lund, 2003).

Lower-priced computers created markets for shrinkwrap software. For the first time, computer and software companies targeted significant numbers of non-technical hands-on users who received little or no formal training. It had taken twenty years, but early visions were being realized! Non-programmers were choosing to use computers to do their work. The psychology of discretionary users intrigued two groups: (i) psychologists who liked to use computers, and (ii) technology companies who wanted to sell to discretionary users. Not surprisingly, computer and telecommunication companies started hiring more experimental psychologists.

Discretion in Computer Use

Technology use lies on a continuum bracketed by the assembly line nightmare of *Modern Times* and the utopian vision of completely empowered individuals. To use a technology or not to use it—sometimes we have a choice, other times we don't. On the phone, we may have to wrestle with speech recognition and routing systems. At home, computer use may be largely discretionary. The workplace often lies in-between: Technologies are prescribed or proscribed, but we ignore some injunctions or obtain exceptions, we use some features but not others, and we join with colleagues to press for changes.

For early computer builders, work was more a calling than a job, but operation required a staff to carry out essential if less interesting tasks. For the first half of the computing era, most hands-on use was by people with a mandate. Hardware innovation, more versatile software, and steady progress in understanding the psychology of users and tasks—and transferring that understanding to software developers—led to hands-on users who had more choice regarding how they worked. Rising expectations played a role; people learned that software is flexible and expected it to be more congenial. Competition among vendors produced alternatives. With more emphasis on marketing to consumers came more emphasis on user-friendliness.

Discretion is not all-or-none. No one must use a computer, but many jobs and pastimes require it. People can resist, sabotage, or quit their jobs. However, a clerk or a systems administrator has less discretion than someone using technology for a leisure activity. For an airline reservation clerk, computer use is mandatory. For a traveler booking a flight, computer use is discretionary. This distinction, and the shift toward greater discretion, is at the heart of the history of HCI.

The shift was gradual. Over thirty years ago, John Bennett (1979) predicted that discretionary use would lead to more emphasis on usability. The 1980 book *Human Interaction with Computers*, edited by Harold Smith and Thomas

Green, perched on the cusp. It included an article by Jens Rasmussen, "The Human As a Systems Component," that covered the nondiscretionary perspective. One-third of the book covered research on programming. The remainder addressed "non-specialist people," discretionary users who are not computer-savvy. Smith and Green wrote, "It's not enough just to establish what computer systems can and cannot do; we need to spend just as much effort establishing what people can *and want to do*." (p. viii, italics in original.)

A decade later, Liam Bannon (1991) noted broader implications of a shift "from human factors to human actors." The trajectory is not always toward choice. Discretion can be curtailed—for example, word processor use is now often a job requirement, not an alternative to using a typewriter. Even in an era of specialization, customization, and competition, the exercise of choice varies over time and across contexts. Discretion is only one factor, but an analysis of its role casts light on how HCI efforts differ and why they have remained distinct through the years.

Minicomputers and Office Automation

Cabinet-sized mini-computers that could support several people were available from the mid-1960s. By the late 1970s, super-minis such as the VAX 11/780 supported integrated suites of productivity tools. In 1980, Digital Equipment Corporation, Data General, and Wang Laboratories were growth companies near Boston.

A minicomputer could handle personal productivity tools or a database of moderate size. Users sat at terminals. With 'dumb terminals,' the central processor handled each keystroke. Other terminals had a processor that supported a user who entered a screenfull of data, which was then on command sent as a batch to the central processor. These minis could provide a small group (or 'office') with file sharing, word processing, spreadsheets, and email, and manage output devices. They were marketed as 'office systems,' 'office automation systems,' or 'office information systems.'

The 1980 Stanford International Symposium on Office Automation, with two papers by Douglas Engelbart, marked the emergence of a research field that remained influential for a decade, and then faded away (Landau, Bair & Siegman, 1982). Also in 1980, ACM formed the Special Interest Group on Office Automation (SIGOA) and the American Federation of Information Processing Societies (AFIPS, the parent organization of ACM and IEEE at the time) held the first of seven annual Office Automation conferences and product exhibitions. In 1982, SIGOA initiated the biennial Conference on Office Information Systems (COIS) and the first issue of the journal *Office: Technology and People* appeared, followed in 1983 by *ACM Transactions on Office Information Systems (TOOIS)*.

You might ask, "what is all this with offices?" Minicomputers brought down the price of computers to fit into the budget of a small work-group: an 'office.' (The attentive reader will anticipate: The personal computer era is approaching!) Office Information Systems, which focused on the use of minicomputers, was positioned alongside Management Information Systems, which focused on mainframes. Its scope was reflected in the charter of *TOOIS*: database theory, artificial intelligence, behavioral studies, organizational theory, and communications. Minis were accessible to database researchers. Digital's PDP series was a favorite of AI researchers until LISP machines arrived. Minis were familiar to behavioral researchers who used them to run and analyze psychology experiments. Computer-mediated communication (CMC) was an intriguing new capability: Networking was still rare, but people at different terminals of a minicomputer could exchange email or chat in real time. Minis became interactive computers of choice for many organizations. As a consequence, Digital became the second largest computer company in the world and Dr. Wang the fourth wealthiest American.

The researchers were discretionary users, but few office workers chose their tools. The term 'automation' was challenging and exciting to researchers, but it conjured up less pleasant images for office workers. Some researchers, too, preferred Engelbart's focus on augmentation rather than automation.

Papers in the SIGOA newsletter, COIS, and *TOOIS* included technical work on database theory, a modest number of AI papers (the AI winter had not yet ended), decision support and CMC papers from the IS community, and behavioral studies by researchers who later joined CHI. IS papers were prevalent in the newsletter, whereas *TOOIS* favored technical papers and was a principal outlet for behavioral studies until the journal *Human-Computer Interaction* started in 1985.

Although OA/OIS research was eventually absorbed by other fields, it identified and called attention to important emerging topics, including hypertext, computer-mediated communication, and collaboration support. OIS research conceptually overlapped the technical side of information science, notably in information retrieval and language processing.

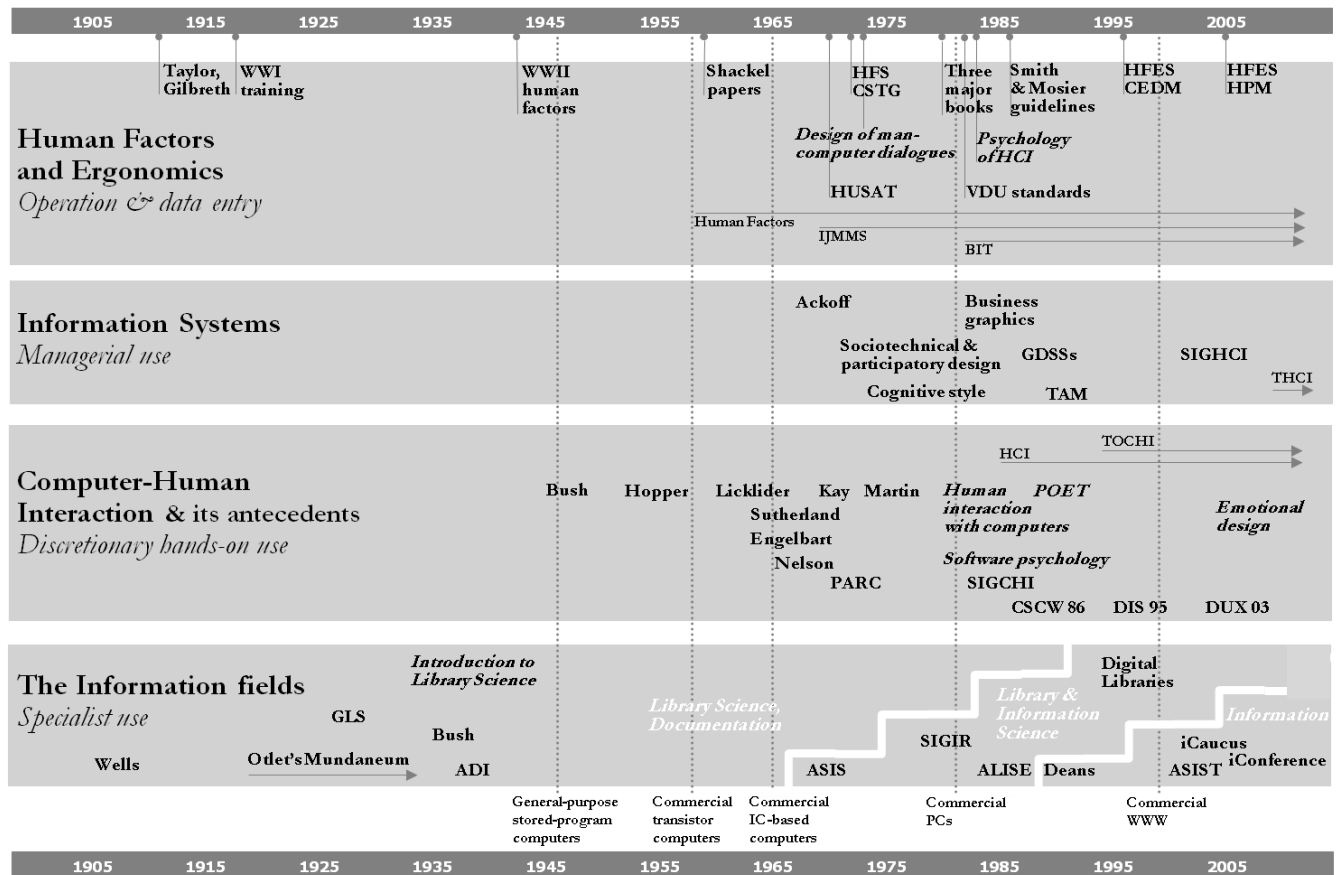


Figure 1. Four fields with major HCI research threads. Acronym expansions are in the text.

The Formation of ACM SIGCHI

Figure 1 identifies research fields that directly bear on HCI. Human Factors and Information Systems have distinct subgroups that focus on use of digital technologies. Relevant Computer Science research is concentrated in CHI, the subgroup primarily concerned with discretionary hands-on computer use. Other computer science influences—computer graphics, artificial intelligence, office systems—have been discussed in the text but are not included in Figure 1. The fourth field, Information, began as support for specialists but may come to exert the broadest influence of all.

Decreasing microcomputer prices attracted discretionary hobbyists. In 1980, as IBM prepared to launch the PC, a groundswell of attention to computer user behavior was building. IBM, which like many hardware companies had not sold software separately, had decided to make software a product focus. Several cognitive psychologists joined an IBM group that included John Gould, who had been publishing human factors research since the late 1960s. They initiated empirical studies of programming and studies of software design and use. Other psychologists who in 1980 led recently formed HCI groups were Phil Barnard at the Medical Research Council Applied Psychology Unit in Cambridge, England (which drew funding from IBM and British Telecom); Tom Landauer at Bell Laboratories; Donald Norman at the University of California, San Diego; and John Whiteside at Digital Equipment Corp.

From one perspective, CHI was formed by psychologists who saw an opportunity to shape a better future. From another, it was formed by managers in computer and telecommunications companies who saw that digital technology would soon be in the hands of millions of technically unsophisticated users whose interaction needs were unknown. Invention or evolution based on empirical observation-- competing views of CHI's role or roles were present from the outset.

Xerox PARC and CMU collaborators influenced the field in several ways, described in this section and the next. The 1981 Xerox Star, with its carefully designed graphical user interface, was not a commercial success (nor were a flurry of GUIs that followed, including the Apple Lisa), but it influenced researchers and developers—and the design of the Macintosh.

Communications of the ACM created a “Human Aspects of Computing” department in 1980. The next year, Tom Moran edited a special issue of *Computing Surveys* on “The Psychology of the Computer User.” Also in 1981, the ACM Special Interest Group on Social and Behavioral Science Computing (SIGSOC) extended its workshop to cover interactive software design and use. In 1982 a conference in Gaithersburg, Maryland on “Human Factors in Compu-

ting Systems” was unexpectedly well-attended. Shortly afterward, SIGSOC shifted its focus to Computer-Human Interaction and changed its name to SIGCHI (Borman, 1996).

In 1983, the first CHI conference attracted more than 1000 people. Half of the 58 papers were from the aforementioned eight research labs. Cognitive psychologists in industry dominated the program, although the Human Factors Society co-sponsored the conference and contributed the program chair Richard Pew, committee members Sid Smith, H. Rudy Ramsay, and Paul Green, and several presenters. Brian Shackel and HFS president Robert Williges gave tutorials on the first day. The International Conference on Human-Computer Interaction (INTERACT), first held in London in 1984 and chaired by Shackel, drew HF&E and CHI researchers.

The first profession to become discretionary hands-on users was computer programming, as paper coding sheets were discarded in favor of text editing at interactive terminals, PCs, and small minicomputers. Therefore, many early CHI papers, by Ruven Brooks, Bill Curtis, Thomas Green, Ben Shneiderman, and others, continued the psychology-of-programming research thread. Shneiderman formed the influential HCI Laboratory (HCIL) at Maryland in 1983. IBM T.J. Watson Research Center also contributed, as noted by John Thomas (personal communication, October 2003):

One of the main themes of the early work was basically that we in IBM were afraid that the market for computing would be limited by the number of people who could program complex systems, so we wanted to find ways for “nonprogrammers” to be able, essentially, to program.

The prevalence of experimental psychologists studying text editing was captured by Thomas Green's remark at INTERACT'84 that “text editors are the white rats of HCI.” As personal computing spread, experimental methods were applied to study other contexts involving discretionary use. Studies of programming gradually disappeared from HCI conferences.

CHI focused on novice use. Initial experience is particularly important for discretionary users, and therefore also for the vendors developing software that people use by choice. Novice users are also a natural focus when a new technology is involved and when each year saw more people take up computing than did the previous year.

Routinized heavy use was still widespread. Databases were used by airlines, banks, government agencies, and other organizations. This hands-on activity was rarely discretionary. Managers oversaw development and analyzed data, leaving data entry and information retrieval to people hired for those jobs. To improve skilled data handling required a human factors approach. CHI studies of database use were few—I count three over a decade, all focused on novice or casual use.

Fewer European companies produced mass-market software. European HCI research focused on in-house development and use, as reflected in the journal *Behaviour & Information Technology*, which was launched in 1982 by Tom Stewart and published by Taylor & Francis in London. In his perceptive essay cited above, Bannon urged that more attention be paid to discretionary use, yet criticized CHI's heavy emphasis on initial experiences, perhaps reflecting the European perspective. At Loughborough University, HUSAT focused on job design (the division of labor between people and systems) and collaborated with the Institute for Consumer Ergonomics, particularly on product safety. In 1984, Loughborough initiated an HCI graduate program drawing on human factors, industrial engineering, and computer science.

The work of early visionaries was unfamiliar to many CHI researchers who helped realize some of the visions. The 633 references in the 58 papers presented at CHI'83 included many authored by cognitive scientists, but Bush, Sutherland, and Engelbart were not cited. A few years later, computer scientists familiar with the early work joined CHI, notably those working on computer graphics. The psychologists eventually discovered and identified with the pioneers, who shared their concern for discretionary use. This conceptual continuity bestowed legitimacy on a young enterprise that sought to establish itself academically and professionally.

CHI and Human Factors Diverge

Hard science, in the form of engineering, drives out soft science, in the form of human factors. — Newell and Card (1985, p. 212)

Between 1980 and 1985, Card, Moran, and Newell (1980a,b) introduced a “keystroke-level model for user performance time with interactive systems.” This was followed by the cognitive model GOMS—goals operators, methods, and selection rules—in their landmark 1983 book, *The Psychology of Human-Computer Interaction*. Although highly respected by the cognitive psychologists prevalent in CHI at the time, these models did not address discretionary, novice use. They focused on the repetitive expert use studied in human factors. GOMS was explicitly positioned to counter the stimulus-response bias of human factors research:

Human-factors specialists, ergonomists, and human engineers will find that we have synthesized ideas from modern cognitive psychology and artificial intelligence with the old methods of task analysis... The user is not an operator. He does not operate the computer, he communicates with it... (p. viii)

Newell and Card (1985) noted that human factors had a role in design, but continued:

Classical human factors... has all the earmarks of second-class status. (Our approach) avoids continuation of the classical human-factors role (by transforming) the psychology of the interface into a hard science. (p. 221)

In 2004, Card noted in an email discussion:

Human Factors was the discipline we were trying to improve... I personally changed the (CHI conference) call in 1986, so as to emphasize computer science and reduce the emphasis on cognitive science, because I was afraid that it would just become human factors again.

Ultimately, human performance modeling drew a modest but fervent CHI following. Key goals differed from those of other researchers and many practitioners. "The central idea behind the model is that the time for an expert to do a task on an interactive system is determined by the time it takes to do the keystrokes," wrote Card, Moran & Newell (1980b, p. 397). Modeling was extended to a range of cognitive processes, but it was most useful in helping to design for nondiscretionary users, such as telephone operators engaged in repetitive tasks (e.g., Gray et al., 1990). Its role in augmenting human intellect was unclear.

CHI and Human Factors moved apart, although "Human Factors in Computing Systems" remains the CHI conference subtitle. They were never highly integrated. Most of the cognitive psychologists had turned to HCI after earning their degrees and were unfamiliar with the human factors literature. The Human Factors Society did not again co-sponsor CHI. Its researchers disappeared from the CHI program committee. Most CHI researchers who had published in the human factors literature shifted to CHI, *Communications of the ACM*, and the journal *Human-Computer Interaction* launched in 1985 by Thomas Moran and published by Erlbaum, a publisher of psychology books and journals.

The shift was reflected at IBM. John Gould and Clayton Lewis authored a CHI 83 paper that nicely framed the CHI focus on user-centered, iterative design based on prototyping. Cognitive scientists at IBM helped shape CHI, but Gould's principal focus remained human factors; he served as HFS president four years later. Reflecting the broader change, in 1984 the Human Factors Group at Watson faded away and a User Interface Institute emerged.

CHI researchers, identifying with 'hard' science or engineering, adopted the terms 'cognitive engineering' and 'usability engineering.' In the first paper presented at CHI'83, "Design Principles for Human-Computer Interfaces," Donald Norman applied engineering techniques to discretionary use, creating 'user satisfaction functions' based on technical parameters. These functions would not hold up long—people are fickle, yesterday's satisfying technology is not as gratifying today—but it would be years before CHI loosened its identification with engineering and truly welcomed Design and other disciplines.

Workstations and Another AI Summer

High-end workstations from Apollo, Sun, and Silicon Graphics appeared between 1981 and 1984. Graphics researchers no longer had to flock to heavily-financed laboratories (notably MIT and Utah in the 1960s; MIT, NYIT, and PARC in the 1970s). Workstations were too expensive to reach a mass market, so graphics research that focused on photorealism and animation, which required the processing power of these machines, did not directly exert a broad influence on HCI.

The Xerox Star (formally named Office Workstation), Apple Lisa, and other commercial GUIs appeared, but when the first CHI conference was held in December, 1983, none were commercial successes. They cost too much or ran on processors that were too weak to exploit graphics effectively.

In 1981, Symbolics and LMI introduced workstations optimized for the LISP programming language favored by most AI researchers. The timing was fortuitous. In October of that year, a conference called Next Generation Technology was held in the National Chamber of Commerce auditorium in Tokyo, and in 1982 the Japanese government established the Institute for New Generation Computer Technology (ICOT) and a ten-year Fifth Generation project focused on AI. AI researchers in Europe and the United States sounded the alarm. Donald Michie of Edinburgh saw a threat to Western computer technology, and in 1983, Ed Feigenbaum of Stanford and Pamela McCorduck wrote:

The Japanese are planning the miracle product... They're going to give the world the next generation—the Fifth Generation—of computers, and those machines are going to be intelligent... We stand, however, before a singularity, an event so unprecedented that predictions are almost silly... Who can say how universal access to machine-intelligence—faster, deeper, better than human intelligence—will change science, economics, and warfare, and the whole intellectual and sociological development of mankind? (pp. 8–9, 287.)

Parallel distributed processing (often called 'neural network') models also seized the attention of researchers and the media. Used for modeling phenomena including signal detection, motor control, and semantic processing, neural networks represented conceptual and technical advances over earlier AI work on perceptrons. Their rise was tied to the new generation of minicomputers and workstations, which had the power to support simulation experiments. Production systems, a computer-intensive AI modeling approach with a psychological foundation, developed at CMU, also gained the attention of researchers.

These developments triggered an artificial intelligence gold rush. As with actual gold rushes, most of the money was made by those who outfitted and provisioned the prospectors, although generous government funding again flowed to the actual researchers. The European ESPRIT and UK Alvey programs invested over US\$200M per year starting in 1984 (Oakley, 1990). In the United States, funding for the DARPA Strategic Computing AI program, begun in 1983, rose to almost \$400M in 1988 (Norberg & O'Neill, 1996). Investment in AI by 150 U.S. companies was estimated at about \$2B in 1985 (Kao, 1998).

The unfulfilled promises of the past led to changes this time around. General problem solving was emphasized less, whereas domain-specific problem solving was emphasized more. Terms such as intelligent knowledge-based systems, knowledge engineering, expert systems, machine learning, language understanding, image understanding, neural networks, and robotics were often favored over AI.

In 1983, Raj Reddy of CMU and Victor Zue of MIT criticized the mid-1970s abandonment of speech processing research, and soon funds again became plentiful for these research topics (Norberg & O'Neill, 1996, p. 238). Johnson (1985) estimated that 800 corporate employees and 400 academics were working on natural language processing research. Commercial natural language understanding (NLU) interfaces to databases such as AI Corporation's Intellect and Microrim Clout appeared.

The optimism is illustrated by two meticulously researched Ovum reports on speech and language processing (Johnson, 1985; Engelen & McBride, 1991). In 1985, speech and language product "revenue" was US\$75 million, comprising mostly income from grants and investor capital. That year, Ovum projected that sales would reach \$750 million by 1990 and \$2.75 billion by 1995. In 1991, sales were under \$90 million, but hope springs eternal and Ovum forecast \$490 million for 1995 and \$3.6 billion for 2000.

About 20 U.S. corporations banded together, jointly funding the Microelectronics and Computer Technology Corporation (MCC). U.S. antitrust laws were relaxed to facilitate this cooperation. MCC embraced AI, reportedly becoming the leading customer for both Symbolics and LMI. MCC projects included two parallel NLU efforts, work on intelligent advising, and CYC (as in "encyclopedic," and later spelled Cyc), Douglas Lenat's ambitious project to build a common-sense knowledge base that other programs could exploit. In 1984, Lenat predicted that by 1994 CYC would be intelligent enough to educate itself. Five years later CYC was reported to be on schedule and about to "spark a vastly greater renaissance in [machine learning]" (Lenat, 1989, p. 257).

Knowledge engineering involved human interaction. This could have brought AI closer to HCI, but AI researchers who were interested in representation and reasoning were frustrated by the difficulty of eliciting knowledge from experts. Many AI systems were aimed at non-discretionary use, creating opportunities for HF&E, especially in Europe, where funding directives dictated work that spanned technical and behavioral concerns. The journal *IJMMS* became a major outlet for both HF&E and AI research in the 1980s.

Interaction of AI and CHI was limited. CHI'83 and CHI'85 had sessions on speech and language, cognitive modeling, knowledge-based help, and knowledge elicitation. Not many AI researchers and developers worried about interaction details. For example, they loved powerful tools such as EMACS and UNIX, forgetting the painful weeks that had been required to master the badly-designed command languages. And AI technologies did not succeed in the marketplace. Before it disappeared, AI Corporation's primary customer for the database interface Intellect was the government, where discretionary use was not the norm.

1985–1995: GRAPHICAL USER INTERFACES SUCCEED

"There will never be a mouse at the Ford Motor Company."
—A high-level acquisition manager, 1985 (personal communication)

When graphical user interfaces finally succeeded commercially, they were a 'disruptive revolution' that transformed HCI. As with previous major shifts—to stored programs and to interaction based on commands, full-screen forms and full-screen menus—some people were affected before others. GUIs were especially attractive to consumers, to new or casual users. Their success immediately transformed CHI, but only after Windows 3.0 succeeded in 1990 did GUIs influence the government agencies and business organizations that are the focus of HF&E and IS researchers. By 1990, the technology was better understood and thus less disruptive. The early 1990s also saw the maturation of local area networking and the Internet, producing a second transformation: computer-mediated communication and information sharing.

CHI Embraces Computer Science

Apple launched the Macintosh with a 1984 Super Bowl ad describing office work, but sales did not follow and by mid-1985 Apple was in trouble. Then Macs appeared with four times as much random-access memory (RAM), which was sufficient to manage Aldus PageMaker, Adobe Postscript, the Apple LaserWriter, and Microsoft's Excel and Word for Macintosh as they were released. The more powerful Mac Plus arrived in January, 1986. Rescued by hardware and software advances, the Mac succeeded where the commercial GUIs before it could not. It was popular with consumers and became the platform for desktop publishing.

Within CHI, GUIs were initially controversial. They had disadvantages: An extra level of interface code increased development complexity and created reliability challenges. They consumed processor cycles and distanced users from the underlying system that, many believed, experienced users would eventually want to master. Carroll and Ma-

zur (1986) showed that GUIs confused and created problems for people familiar with existing interfaces. An influential 1986 essay on direct manipulation interfaces, Hutchins, Hollan, and Norman concluded, “It is too early to tell” how GUIs would fare. GUIs could well prove useful for novices, they wrote, but “we would not be surprised if experts are slower with Direct Manipulation systems than with command language systems” (p. 121, italics in original). Given that most prior HCI research focused on expert use, this insight seemed significant. However, first-time use proved critical in the rapidly expanding consumer market and hardware and software improvements overcame some early limitations. GUIs were here to stay, and CHI was soon transformed. Previously active topics of research, including command naming, text editing, and the psychology of programming, were abandoned. More technical topics, such as ‘user interface management systems,’ became significant.

Viewed from a higher plane, psychology gave way to computer science as the driving force in interaction design. Researchers had strived for a comprehensive, theoretical, psychological framework based on formal experiments (Newell & Card, 1985; Carroll & Campbell, 1986; Long, 1989; Barnard, 1991). Such a framework was conceivable for constrained command- and form-based interaction, but could not be scaled to design spaces that included color, sound, animation, and an endless variety of icons, menu designs, and window arrangements. The new mission was to identify the most pressing problems and find satisfactory rather than optimal solutions. Rigorous experimentation, a skill of cognitive psychologists, gave way to quicker, less precise assessment methods, championed by Jakob Nielsen (1989; Nielsen & Molich, 1990).

Exploration of the dynamically evolving, less constrained design space required software engineering expertise. The late 1980s saw an influx of computer scientists to the CHI community. HCI entered the curricula of many computer science departments. CHI became a natural home to many computer scientists working on interactive graphics, to software engineers interested in interaction, and to some AI researchers working on speech recognition, language understanding, and expert systems. In 1994, ACM launched *Transactions on Computer-Human Interaction (TOCHI)*. Early PCs and Macs were not easily networked, but as the use of local area networks spread, CHI’s focus expanded to include collaboration support, bringing CHI into contact with MIS and OA research efforts discussed below.

HF&E Maintains a Nondiscretionary Use Focus

Human Factors and Ergonomics research continued to respond to the needs of government agencies, the military, aviation, and telecommunications industries. Governments are the largest consumers of computing, for census, tax, social security, health and welfare, power plant operation, air traffic control, ground control for space missions, military logistics, text and voice processing for intelligence, and so on. The focus is on skilled use—users are assigned technology and trained if necessary. For routine data entry and other tasks, small efficiency gains in individual transactions can yield large benefits over time, justifying the effort to make improvements that might not be noticed by discretionary users. After SIGCHI formed, the Human Factors Society undertook a study to see how it would affect membership in its Computer Systems Technical Group. An unexpectedly small membership overlap was found (Richard Pew, personal communication, September 2004). The organizations had different goals.

Government agencies promoted the development of ergonomic standards to help in defining system requirements for competitive bidding while remaining at arms’ length from potential developers, who of course better understand technical possibilities and helped with standards development. Compliance with standards could then be specified in a contract. In 1986, Sid Smith and Jane Mosier published the last of a series of government-sponsored interface guidelines, with 944 design guidelines organized into sections titled Data Entry, Data Display, Data Transmission, Data Protection, Sequence Control, and User Guidance. The authors recognized that GUIs would expand the design space beyond the reach of this already cumbersome document that omitted icons, pull-down and pop-up menus, mice button assignments, sound, animation, and so on. Smith and Mosier foresaw that requirements definition must shift to specify predefined interface styles and design processes rather than features that would be built from scratch.

DARPA’s heavily-funded Strategic Computing AI program set out to develop an Autonomous Land Vehicle, a Pilot’s Associate, and a Battle Management system. All raised human factors research issues. These systems were to include interactive technologies such as speech recognition, language understanding, and heads-up displays. People might avoid these technologies when given a choice, but pilots, those guiding autonomous vehicles, and officers under stressful conditions might have no better alternative. Speech and language technologies have other nondiscretionary potential, some of it civilian: for translators and intelligence analysts, when a phone system provides no alternative, when a disability limits keyboard use, or when hands are otherwise occupied.

IS Extends Its Range

Although GUIs were not quickly adopted by organizations, spreadsheets and business graphics (charts and tables) were important to managers and thus foci of Information Systems research. Remus (1984) contrasted tabular and graphic presentations and Benbasat and Dexter (1985) added color as a factor, although color displays were rare in the 1980s. Many studies contrasted on-line and paper presentation, because most managers worked with printed reports. Although research into individual cognitive styles was abandoned in the early 1980s following a devastating

critique (Huber, 1983), the concept of cognitive fit between task and tool was introduced to explain apparently contradictory results in the adoption literature (Vessey and Galletta, 1991).

A series of symposia on Human Factors in Information Systems was initiated in 1986 by Jane Carey, leading to several books (e.g., Carey, 1988). Topics included user interaction with information, design and development, and as corporate adoption of minicomputers and intranets matured, communication and collaboration, including studies of email use.

The involvement of end users in the development process was actively discussed in IS, but rarely practiced outside of the sociotechnical design and the participatory design movement discussed below (Friedman, 1989). Hands-on managerial use was atypical in this period, but it was central to group decision support systems (GDSS) research. Central to GDSS was support for meetings, including brainstorming, idea organization, and online voting features. GDSS emerged from decision support systems designed for individual executives or managers. These systems were initially too expensive to be mass-market products; hence the focus on 'decision-makers.' Research was conducted primarily in schools of management, not computer science departments or software companies. GDSS research was a major IS contribution to Computer Supported Cooperative Work (CSCW), discussed in the next section. In 1990 three companies, including IBM and a University of Arizona spin-off, began marketing GDSSs, without much success. The systems did well in laboratory studies but were generally not liked (Dennis & Reinicke, 2004), and 'decision-makers' had discretion as to which tools they used. As computing costs came down, GDSS evolved to be 'group support systems' designed for both managerial and non-managerial workers. Computer-supported meeting facility research was conducted in the mid-1980s in several laboratories (e.g., Begeman et al., 1986; DeSanctis and Gallupe, 1987; Dennis et al., 1988). Extensive research at the University of Arizona is summarized in Nunamaker et al. (1997).

The Technology Acceptance Model (TAM) introduced by Davis (1989) led to considerable IS research. TAM and its offspring focus on perceived usefulness and perceived usability to improve "white collar performance" that is "often obstructed by users' unwillingness to accept and use available systems" (p. 319). "An element of uncertainty exists in the minds of decision makers with respect to the successful adoption," wrote Bagozzi, Davis, and Warshaw (1992, p. 664). Although TAM is a managerial view of individual behavior, it was influenced by Davis's exposure to early CHI usability research.

TAM is probably the most cited HCI work in IS. The management view of hands-on computer use as non-discretionary was giving way as use spread to white-collar workers who could refuse to play. TAM's emphasis on *perceived* utility and usability is a key distinction: Consumers choose technologies that they are convinced will be useful—CHI researchers assume utility and focus on the *experience* of usability. TAM researchers focus on utility and note that perceptions of usability can influence acceptance. CHI addressed usability a decade before TAM, albeit actual usability rather than perceived usability. Perception was a secondary 'user satisfaction' measure to CHI researchers, who believed (not entirely correctly) that measurable reduction in time, errors, questions, and training would eventually translate into positive perceptions. The word 'acceptance,' which is the 'A' in TAM, is not in the CHI vocabulary. Discretionary users adopt, they do not accept.

The IS and CHI communities rarely mixed. When CHI was over a decade old, *Harvard Business Review*, a touchstone for IS researchers, published "Usability: The New Dimension of Product Design" (March, 1994). The article did not mention CHI at all. It concluded that "user-centered design is still in its infancy" (p. 149).

Collaboration Support: OIS Gives Way to CSCW

In the late 1980s, three research communities addressed small-group communication and information-sharing: (i) Office Automation/Office Information Systems, described above; (ii) IS researchers building systems to support organizational decision-making could, as computing costs declined, address group decision-making more generally; (iii) The proliferation of local area networks enabled some CHI researchers to move from individual productivity software to the quest for 'killer apps' that would support teams.

OA/OIS had led the way, but was disappearing by 1995. Minicomputers, the platform for most OIS research, did not survive competition from PCs and workstations. The concept of 'office' or group proved to be problematic: Organizations and individuals are persistent entities with goals and needs, but small groups often have ambiguous membership and undergo shifts in character as members join or depart. People in an organization who need to communicate often fall under different budgets, complicating acquisition decisions unless a technology is made available organization-wide.

The rapid shift was reflected in terminology use. First, 'automation' fell out of favor. In 1986, ACM SIGOA shifted to SIGOIS and the annual AFIPS OA conferences were discontinued. By 1991, the term 'office' followed: *Transactions on Office Information Systems* became *Transactions on Information Systems*; *Office: Information and People* became *Information Technology and People*; and 'Conference on Office Information Systems' became 'Conference on Organizational Communication Systems' (COOCS, in 1997 becoming the GROUP Conference).

The AI summer, which contributed to the OA/OIS effort, ended when AI failed to meet expectations: Massive funding did not deliver a Pilot's Associate, an Autonomous Land Vehicle, or a Battle Management System for the military. Nor were offices automated. CHI conference sessions on language processing had diminished prior to this AI winter, but sessions on modeling, adaptive interfaces, advising systems, and other uses of intelligence in interfaces increased through the 1980s before declining in the 1990s. Funding for AI became scarce, employment opportunities

dried up, and conference participation dropped off.

A 1986 conference, building on a successful, private 1984 workshop (Greif, 1985), brought together researchers from diverse disciplines interested in issues of communication, information sharing, and coordination under the banner 'Computer Supported Cooperative Work.' Participants came primarily from IS, OIS, CHI, distributed AI, and anthropology. Four of thirteen CSCW program committee members and many papers were from schools of management, with similar participation by the OIS community.

The field coalesced in 1988. The book *Computer-Supported Cooperative Work*, edited by Irene Greif, was published, and SIGCHI sponsored a biennial North American CSCW conference. A European series (ECSCW) was initiated in 1989. With heavy participation from technology companies, North American CSCW had a small-group focus on networked individuals working on PCs, workstations, or minicomputers. Groups were either within an organization or linked by ARPANET, BITNET, or other networks. European participation, primarily from academia and government agencies, focused on organizational use of technologies. It differed methodologically from most IS research in North America. Scandinavian approaches, described in the next section, were presented at CSCW and were central to ECSCW.

Just as human factors researchers left CHI after a few years, most IS researchers who were involved with CSCW left in the early 1990s. One factor was a shift within IS from social psychology to organizational behavior in studying team behavior. The Hawaii International Conference on System Sciences (HICSS) was becoming a major IS pre-journal publication venue for work with an organizational orientation. In contrast, the organizational focus conflicted with the CSCW interest in context-independent small-group support, which was the realm of social psychology and the goal of many technology companies. Some IS researchers participated in COOCS and a bi-annual Groupware conference series initiated in 1992. The split was not entirely amicable; the IS newsletter *Groupware Report* did not include CSCW on its list of relevant conferences.

The pace of change in technology and use created challenges for CSCW. In 1985, supporting a small team was a technical challenge; ten years later, the Web had arrived. Applications that provided awareness of the activity of distant collaborators was a celebrated achievement in the early 1990s; several years later, dark linings to the silver cloud arose in the form of privacy concerns and information overload. Phenomena were carefully identified, such as a 'productivity paradox' in which IT investments were not returning benefits, and health effects of Internet use by young people, only to vanish in new studies undertaken a few years later. Other changes brought European and North American CSCW into greater alignment. European organizations were starting to acquire commercial software products, a CSCW focus in North America, and North Americans were discovering that organizational context, an ECSCW focus, was often crucial in the design and deployment of products intending to support group activity. Organizational behaviorists and theorists were thriving in their home disciplines, but ethnographers studying technology use, marginalized in traditional anthropology departments, were welcomed into CSCW.

Despite the challenges of building on sands swept by successive waves of technology innovation, CSCW remains a strong research area that attracts a broad swath of HCI researchers. Content ranges from the highly technical to thick ethnographies of workplace activity, from studies of instant messaging dyads to scientific laboratories involving hundreds of people dispersed in space and time. The handbook chapter on Collaboration Technologies by Gary and Judy Olson covers the technical side in depth, with references to other CSCW resources.

Participatory Design and Ethnography

Prior to the 1985 some system developers explored methods to involve future users in designing a system. Typically, the users were non-discretionary users of a system being developed by a large enterprise for its own use. Sociotechnical design took a managerial perspective. Participatory or cooperative design, rooted in the Danish trade union movement, focused on empowering hands-on users (Nygaard, 1977).

Scandinavian approaches influenced human factors (e.g., Rasmussen, 1986) and attracted wide notice with the publication of the proceedings of a conference held in Aarhus, Denmark in 1985 (Bjerknes et al., 1987). Participatory design was a critique of IS approaches, yet the Scandinavians resonated with CHI researchers. Despite differences in culture, contexts of development (in-house system vs. commercial product), and contexts of use (non-discretionary vs. discretionary), they shared the goal of empowering hands-on users. Most were also of the generation that grew up in the 1960s, unlike the World War II generation that dominated HF&E and IS.

Ethnography was a different approach to obtaining deep insights into potential users. Lucy Suchman managed a Xerox PARC group that presented studies of workplace activity at CSCW. Suchman published an influential critique of artificial intelligence in 1987 and a widely-read review of the Aarhus proceedings in 1988, and as program chair she brought many of the Scandinavians to the CSCW 1988 conference.

LIS: An Unfinished Transformation

Research universities have always supported prestigious professional schools, but the prestige of library schools declined with the rise of higher-paid IT and software engineering professions. Between 1978 and 1995, 15 American library schools were shut down (Cronin, 1995, p. 45). Most of the survivors were rechristened Library and Information Science. The humanities orientation had given way and librarianship was being changed by technology. New curricula and faculty with different skills were needed.

The changes did not go smoothly or as anticipated. Forced multidisciplinary is never easy. Exclusion of technology studies may have been a reasonable reaction to the expense and limitations of new technologies. However, Moore's law lowered costs and removed many limitations with such speed that people and organizations had little time to prepare. Young information scientists were not interested in absorbing a century of work on indexing, classifying, and providing access to complex information repositories; their eyes were fixed on a future in which many past lessons would not apply. Those that still applied would likely have to be relearned. The conflicts are exposed in a landmark 1983 collection, *The Study of Information: Interdisciplinary Messages* (Machlup and Mansfield, 1983). In the book, W. Boyd Rayward outlines the humanities-oriented perspective and the technological perspective and argues that there was convergence. His essay is followed by commentaries attacking him from both sides.

In a series of meetings that began in 1988, the new deans of library & information schools at Pittsburgh, Syracuse, Drexel, and subsequently Rutgers discussed approaches to explaining and managing multidisciplinary schools. Despite this progressive effort, Cronin (1995) depicted LIS at loggerheads and in a "deep professional malaise." He suggested that librarianship be cut loose in favor of stronger ties to cognitive and computer sciences. Through the 1990s, several schools dropped the word 'Library' and became schools of Information (Figure 2). More would follow.

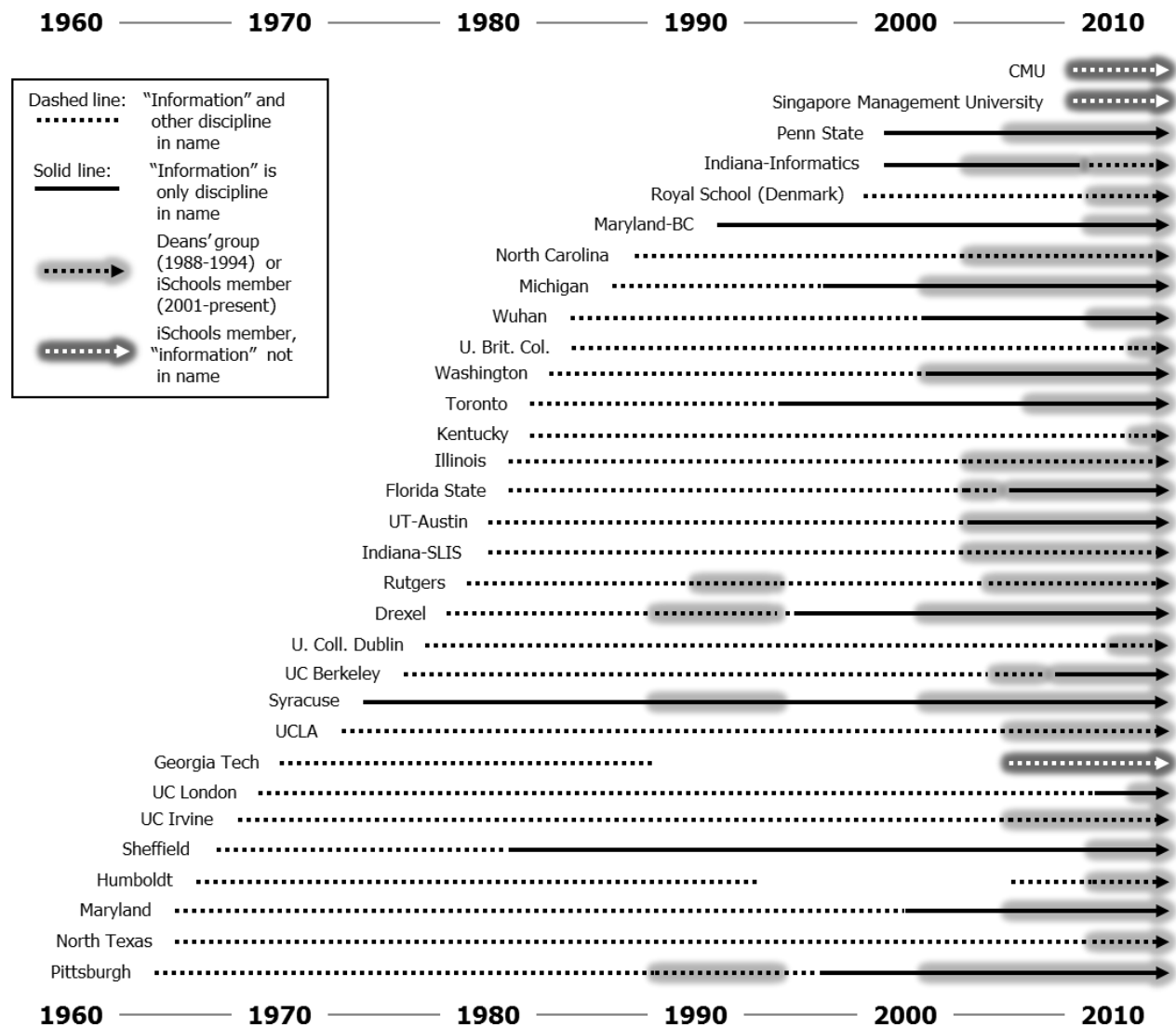


Figure 2. University schools, colleges and faculties and when "information" came into their names (as of 2011).

1995–2010: THE INTERNET ERA ARRIVES

How did the spread of the Internet and the emergence of the Web affect HCI research threads? CHI researchers were Internet-savvy. Although excited by the prospects, they took these changes in stride. Over time, CHI-related research, development, and use evolved. The Internet and the Web were not disruptive to HF&E, either. The Web was initially a return to a form-driven interface style, and it was rarely a locus of routine work anyway. However, the Web had a seismic impact on Information Systems and on Information Science, so this section begins with these disciplines.

The Formation of AIS SIGHCI

The use of computers in organizations has changed. Organizations are no longer focused on maximizing computer use—almost everywhere, screen savers have become the main consumer of processor cycles. The Internet created more porous organizational boundaries. Employees in many organizations could download instant messaging clients, music players, web apps, and other software despite IT concerns about productivity and security. These are not the high-overhead applications of the past. Facebook, Twitter, and myriad other applications and services can be used from a web browser without a download. Experience with technology at home leaves employees impatient with poor software at work. In addition, many managers who were once hands-off users became late adopters in the late 1990s or were replaced by younger managers. Increasingly, managers and executives are hands-on early adopters of some technologies.

Significant as these changes are, the Web had a more dramatic effect on organizational information systems. Corporate IT groups had focused solely on internal operations. They lived inside firewalls. Their customers were other employees. Suddenly, organizations were scrambling to create Web interfaces to external vendors and customers. Discretionary users! The Internet bubble burst, revealing that IT professionals, IS experts, and everyone else had limited understanding of Web phenomena. Nevertheless, on-line marketing, services, and business-to-business systems continued to grow. For many, the Web had become an essential business tool. In handling external customers, IT professionals and IS researchers were in much the same place that CHI was 20 years earlier, whether they realized it or (most often) not.

In 2001, the Association for Information Systems (AIS) established the Special Interest Group in Human–Computer Interaction (SIGHCI). The founders defined HCI by citing 12 CHI research papers (Zhang et al., 2004, p. 148). Bridging to the CHI and to the Information Science communities was declared a priority. The charter of SIGHCI includes a broad range of organizational issues, but its publications emphasize interface design for e-commerce, online shopping, online behavior “especially in the Internet era” (Zhang, 2004, p. 1), and effects of Web-based interfaces on attitudes and perceptions. Eight of the first ten papers in SIGHCI-sponsored journal issues covered Internet and Web behavior.

In 2009, *AIS Transactions on Human–Computer Interaction* was launched. The shift from an organizational focus to the Web and broader end-user computing is documented in Zhang et al.’s (2009) analysis of the IS literature from 1990 to 2008. This survey omits CHI from a list of the fields related to AIS SIGHCI. The bridging effort had foundered, as had three previous efforts to bridge to CHI: from Human Factors, Office Information Systems, and the earlier IS presence in CSCW.

Digital Libraries and the Evolution of LIS

By 1995, an information wave had swept through many universities (Figure 2). Digital technology was in the LIS curriculum. Familiarity with technology use was a prerequisite for librarianship. However, innovative research had not kept pace with professional training (Cronin, 1995).

The Internet grew exponentially, but in 1995 it was still a niche activity found mainly on campuses. In the mid-1990s, Gopher, a convenient system for downloading files over the Internet, attracted attention as a possible springboard for indexing distributed materials. Wells’s (1938) ‘world brain’ seemed to be within reach. The Web hit, accelerating the transformation of information acquisition, management, and access. Between 1994 and 1999, two NSF/DARPA/NASA/National Library of Medicine/Library of Congress/National Endowment for the Humanities/FBI initiatives awarded close to US\$200M for digital libraries research and development. This and other investments galvanized the research community. In 2000 the American Society for Information Science appended ‘and Technology’ to its name to become ASIST.

By 2000, ten Schools (or equivalent units) had information as the sole discipline in their names; today it is twice that. In 2001, a series of ‘deans meetings’ began, which were modeled on those of the late 1980s. The original members, Syracuse, Pittsburgh, and Drexel, were joined by Michigan, Berkeley, and the University of Washington. All are now information schools. In 2005, the first annual ‘iConference’ drew participants from nineteen universities that had

information programs. As of 2012, the 'iCaucus' has 36 dues-paying members. Some are transformed library schools, some have roots in other disciplines, and some formed recently as a school of Information. Collectively, their faculty include HCI researchers trained in each of the four disciplines highlighted in this essay.

Expansion is not without growing pains. Conflicts arise among academic subcultures. The iConference competes with more established conferences in each field. Figure 2 suggests that a shift to a field called Information is well underway, but many faculty still consider themselves "a researcher in {X} who is located in an information school," where X could be library science, HCI, CSCW, IS, communication, education, computer science, or another discipline. We do not know how it will evolve, but we can say with confidence that information has become, and will remain, a significant player in human-computer interaction.

HF&E Embraces Cognitive Approaches

In 1996, HFES formed a new technical group, Cognitive Engineering and Decision Making. It quickly became the largest technical group. A decade earlier this would have been unthinkable: Leading human factors researchers disliked cognitive approaches. The CHI community first adopted the term 'cognitive engineering' (Norman, 1982; 1986)..

Equally astonishing, in 2005 Human Performance Modeling was a new and thriving HFES technical group, initiated by Wayne Gray and Dick Pew, who had been active in CHI in the 1980s. Card, Moran, and Newell (1983) had introduced human performance modeling to reform the discipline of human factors from without. Some work focused on expert performance continued within CHI for a time (e.g., a special issue of *Human-Computer Interaction*, Vol. 12, Number 4, 1997), but now the reform effort has moved within HF&E, where it remains focused largely on non-discretionary use.

Government funding of HCI was largely shaped by the focus of HF&E. The Interactive Systems Program of the U.S. National Science Foundation—subsequently renamed Human-Computer Interaction—was described thus:

The Interactive Systems Program considers scientific and engineering research oriented toward the enhancement of human-computer communications and interactions in all modalities. These modalities include speech/language, sound, images and, in general, any single or multiple, sequential, or concurrent, human-computer input, output, or action." (National Science Foundation, 1993)

One NSF program manager identified his proudest accomplishment to be doubling the already ample funding for natural language understanding research. Even after NSF established a separate Human Language and Communication Program in 2003, speech and language research was heavily supported by both the HCI and Accessibility Programs, with lighter support from AI and other programs. Subsequent NSF HCI program managers emphasized 'direct brain interfaces' or 'brain-computer interaction.' A review committee noted that a random sample of NSF HCI grants included none by prominent CHI researchers (National Science Foundation 2003). NSF program managers rarely attended CHI conferences, which had little on speech, language, or direct brain interaction. These technologies may prove useful and find a place at CHI, but use in discretionary home and office contexts is likely to remain limited.

CHI Evolves and Embraces Design

The steady flow of new hardware, software features, applications, and systems ensures that people are always encountering and adopting digital technologies for the first time. This is important to technology producers, and it generates new research issues. CHI has responded by generally focusing on an innovation when it starts to attract a wide audience.

As an application matures, its use often becomes routine. Technologies such as email and word processing, no longer discretionary for most of us, get less attention from CHI researchers whose gaze is directed to the discretionary use frontier of the moment: Web design, ubiquitous and mobile computing, social computing, Wikipedia use, and so on. New issues include information overload, privacy, and effects of multitasking; methods gaining currency include ethnography and data mining. At a higher level, continuity is present in CHI: exploration of input devices, communication channels, information visualization techniques, and design methods. Proposals to build HCI theory on these shifting sands (Barnard et al., 2000; Carroll, 2003) remain largely aspirational.

Expanding participation in the Internet as its reliability and bandwidth increased steadily through the mid-1990s brought real-time and quasi-real-time communication technologies such as email into greater focus. The Web temporarily slowed this by shifting attention to indirect interaction with static sites, but with the arrival of Web 2.0 and greater support for animation and video, the pace quickened. The Web was like a new continent. Explorers posted flags here and there. Then came attempts at settlement with the virtual worlds research and development that blossomed in the late 1990s. Few of the early pioneers survived; there was little to do in virtual worlds other than chat and play games. But slowly some people shifted major portions of their work and play online, relying on online information sources, digital photo management, social software, digital documents, online shopping, multiplayer games, and so on. This evolution is reflected in CHI

The content of CSCW in North America shifted in response to the extraordinary growth of social networking sites,

Wikipedia, multiplayer games, and other Web phenomena. These are of intrinsic interest to students, and the primarily North American software companies that produce them vie to hire good students and consult with strong senior researchers. These technologies are not yet of great interest to the organizations and government agencies that are the customer for European CSCW research. The convergence of CSCW and ECSCW interests has been undone. Europeans are more focused on basic research in vertical domains. The division resembles that of 20 years ago, brought about by a new generation of technology. In time the two research threads may again converge, perhaps under a new name: “computer supported cooperative work” is outdated. Many digital devices are not considered computers, they play central rather than support roles, activities around them can be competitive or conflictual, and they may be used more for recreation than work.

The Web curtailed research into one thread of AI research: powerful, self-contained personal productivity tools. Considerable effort is required to embed knowledge in application software. When access to external information sources was limited, it was worth trying to embed static, self-contained knowledge, but with today’s easy access to information and knowledgeable people online, it is not promising. In contrast, adaptive systems that merge and filter local and Internet-based information have a role to play. Steady progress in machine learning is enhancing productivity tools—although implausible AI forecasts of the ultra-intelligent Singularity still bloom.

To the psychologists and computer scientists who formed the early CHI community, interface design was a matter of science and engineering. They focused on performance and assumed that people eventually choose efficient alternatives. Because human discretion involves aesthetic preferences and invites marketing and non-rational persuasion, this view was not sustained when computing costs came down. This engineering orientation gripped CHI longer than SIGGRAPH, where aesthetic appeal was a major driver. CHI researchers eventually came around, labeling the study of enjoyment “funology” (Blythe et al., 2003) lest someone think that they were having too good a time.

Some visual designers participated in graphical interface research early on. Aaron Marcus began working full time on computer graphics in the late 1960s. William Bowman’s 1968 book *Graphic Communication* was a strong influence on the design of the Xerox Star, for which the designer Norm Cox’s icons were chosen (Bewley et al., 1983). However, graphic design was considered a secondary activity (Evenson, 2005). In 1995, building on workshops at previous conferences, SIGCHI initiated Designing Interactive Systems (DIS), a biennial conference. Despite aspirations to be broader, DIS draws more system designers than visual designers. In 2003, SIGCHI, SIGGRAPH, and the American Institute of Graphic Arts (AIGA) initiated the Designing for User Experience (DUX) conference series that fully embraced visual and commercial design. The collaboration lasted only through 2007, but it established the significance of Design, which is not typically assessed in research papers. The changing sensibility is reflected in *ACM Interactions*, a magazine launched by CHI in 1994, which has steadily increased the focus on visual design, in both its content and its appearance.

Design’s first cousin, marketing, has been poorly regarded by the CHI community (Marcus, 2004). Web site design forces the issue. Site owners wish to keep users at a site, whereas users may prefer to escape quickly. Consider supermarkets, which position items that most shoppers want far apart, forcing people to traverse aisles where other products beckon. CHI professionals who align themselves with ‘end users’ face a stakeholder conflict when designing for a web site owner. This was not true in the past: Designers of individual productivity tools had little conflict of interest with prospective customers. Marketing is concerned with identifying and satisfying user needs, as well as shaping them. It will likely find a place in CHI, perhaps labeled ‘brandology.’

Finally, CHI has gradually become more open to work that takes a social or political stance. Accessibility was first addressed in the context of physical constraints. Socioeconomic factors were included in Universal Usability conferences in 2000 and 2003. Sustainability and fitness have emerged as topics. This may reflect a distancing from a sense that engineering should strive for value neutrality, or it could be a bid for relevance by an increasingly academic group, or reflect aging CHI baby boomers who are considering their legacies.

The evolution of CHI is reflected in the influential contributions of Donald Norman. A cognitive scientist who introduced the term cognitive engineering, he presented the first CHI 83 paper. It defined ‘user satisfaction functions’ based on speed of use, ease of learning, required knowledge, and errors. His influential 1988 book *Psychology of Everyday Things (POET)* focused on pragmatic usability. Its 1990 reissue as *Design of Everyday Things* reflected a field refocusing on invention. Fourteen years later he published *Emotional Design: Why We Love (or Hate) Everyday Things*, stressing the role of aesthetics in our response to objects.

LOOKING BACK: CULTURES AND BRIDGES

Despite overlapping interests, in a dynamic environment with shifting alliances, the major threads of human-computer interaction research—human factors and ergonomics, information systems, library and information science, and computer-human interaction—have not merged. They have interacted with each other only sporadically, although not for lack of bridge-building efforts. The Human Factors Society co-organized the first CHI conference. CSCW sought to link CHI and IS. Mergers of OIS with CHI and later CSCW were considered. AIS SIGHCI tried to

engage with CHI. Researchers recently hired into information schools remain active in the other fields.

Even within computer science, bridging is difficult. Researchers interested in interaction left SIGGRAPH to join the CHI community rather than form a bridge. A second opportunity arose 20 years later when standard platforms powerful enough for photorealism loomed, but the DUX conference series managed only three meetings. In the case of artificial intelligence, SIGART and SIGCHI cosponsor the Intelligent User Interface series, but participation has remained outside mainstream HCI. What are the obstacles to more extensive interaction across fields?

Discretion as a Major Differentiator

HF&E and IS arose before discretionary hands-on use was common. The information field only slowly distanced itself from supporting specialists. CHI occupied a new niche: discretionary use by non-experts. HF&E and especially IS researchers considered organizational factors; CHI with few exceptions avoided domain-dependent work. As a consequence, HF&E and IS researchers shared journals. For example, Benbasat and Dexter (1985) was published in *Management Science* and cited five *Human Factors* articles. Apart from the LIS, they quickly focused on broad populations. IS countered its organizational focus by insisting that work be framed by theory, which distanced it from generally atheoretical CHI in particular.

The appropriateness of a research method is tied to the motivation of the researchers. HF&E and CHI were shaped by psychologists trained in experimental testing of hypotheses about behavior, and hypothesis-driven experimentation was also embraced by IS. Experimental subjects agree to follow instructions for an extrinsic reward. This is a reasonable model for nondiscretionary use, but not for discretionary use. CHI researchers relabeled 'subjects' as 'participants,' which sounds volitional, and found that formal experimental studies were usually inappropriate: There were too many variables to test formally and feedback from a few participants was often enough. Laboratory studies of initial or casual discretionary use usually require confirmation in real-world settings anyway, more so than studies of expert or trained behavior, due to the artificial motivation of laboratory study participants.

The same goals apply—fewer errors, faster performance, quicker learning, greater memorability, and being enjoyable—but the emphasis differs. For power plant operation, error reduction is critical, performance enhancement is good, and other goals are less important. For telephone order entry takers, performance is critical, and testing an interface that could shave a few seconds from a repetitive operation requires a formal experiment. In contrast, consumers often respond to visceral appeal and initial experience. In assessing designs for mass markets, avoiding obvious problems can be more important than striving for an optimal solution. Less-rigorous discount usability or cognitive walkthrough methods (Nielsen, 1989; Lewis et al., 1990) can be enough. Relatively time-consuming qualitative approaches, such as contextual design or persona use (Beyer and Holtzblatt, 1998; Pruitt and Adlin, 2006), can provide a deeper understanding when context is critical or new circumstances arise.

CHI largely abandoned its roots in scientific theory and engineering, which does not impress researchers from HF&E or theory-oriented IS. The controversial psychological method of verbal reports, developed by Newell and Simon (1972) and foreshadowed by Gestalt psychology, was applied to design by Clayton Lewis as 'thinking-aloud' (Lewis and Mack, 1982; Lewis, 1983). Perhaps the most widely used CHI method, it led some in the other fields to characterize CHI people as wanting to talk about their experiences instead of doing research.

Disciplinary, Generational, and Regional Cultures

In the humanities, journals are venues for work in progress and serious work is published in books. In engineering and the sciences, conferences are generally for work in progress and journals are repositories for polished work. The disciplines of HF&E, IS, and LIS follow the latter practice. In contrast, for computer science in the United States, conference proceedings became the final destination of most work and journal have lost relevance; outside the United States, it retained a journal focus. A key factor was arguably the decision of ACM to archive conference proceedings once it became practical to assemble and publish them prior to the conference (Grudin, 2010). A difference in preferred channel impedes communication. Researchers in journal cultures chafe at CHI's insistence on high selectivity and polished work. CHI researchers are dismayed by what they see at other conferences and having abandoned journals, they do not seek out the strong work in other fields. Low acceptance rates also damaged the bridge between academic and practitioner cultures: Few practitioner papers are accepted and fewer practitioners attend the conferences.

CHI conferences generally accept 20%-25% of submissions. With a few exceptions, HF&E and IS conferences accept twice that proportion or more. By my estimate, at most 15% of the work in CHI-sponsored conferences reaches journal publication. In contrast, an IS track organizer for HICSS estimated that 80% of research there progressed to a journal (Jay Nunamaker, opening remarks at HICSS-38, January 2004).

Information schools draws on researchers from both the journals-as-archival and conferences-as-archival camps. They struggle with this issue, as have computer scientists outside North America. In both cases, the trend is toward increasing the selectivity and valuation of conference publication.

Even within the English language, differences in language use impede communication. Where CHI refers to

'users,' HF&E and IS used the term 'operators.' Especially in IS, a user could be a manager whose only contact with the computer was reading printed reports. For CHI, 'operator' was demeaning and users were always hands-on users. (In software engineering, 'user' often means 'tool user'—which is to say, developers.) These and many other distinctions may not seem critical, but they lead to serious confusions or misconceptions when reading or listening to work from another discipline.

In HF&E and IS streams, 'task analysis' refers to an organizational decomposition of work, perhaps considering external factors; in CHI 'task analysis' is a cognitive decomposition, such as breaking a text editing move operation into select, cut, select, and paste. In IS, 'implementation' meant organizational deployment; in CHI it was a synonym for development. The terms 'system,' 'application,' and 'evaluation' also had different connotations or denotations in the different fields. Significant misunderstandings resulted from failures to appreciate these differences.

Different perspectives and priorities were also reflected in attitudes toward standards. Many HF&E researchers contributed to standards development, believing that standards contribute to efficiency and innovation. A view widespread in the CHI community was that standards inhibit innovation. Both views have elements of truth, and the positions partly converged as Internet and Web standards were tackled. However, the attitudes reflected the different demands of government contracting and commercial software development. Specifying adherence to standards is a useful tool for those preparing requests for proposals, whereas compliance with standards can make it more difficult for a product to differentiate itself.

Competition for resources was another factor. Computers of modest capability were extremely expensive for much of the time span we have considered. CHI was initially largely driven by the healthy tech industry; whereas research in the other fields was more dependent on government funding that waxed and waned. On upswings, demand for researchers outstripped supply. HCI prospered during AI winters, starting with Sutherland's use of the TX-2 when AI suffered its first setback and recurring with the emergence of major HCI laboratories during the severe AI winter of the late 1970s. When computer science thrived, library schools laboring to create information science programs had to compete with expanding computer science departments that were themselves desperate enough to award faculty positions to graduates of masters programs.

A generational divide was evident in the case of CHI researchers who grew up in the 1960s and 1970s. Many did not share the prior generation's orientation toward military, government, and business systems, and reacted negatively to the lack of gender neutrality that is still occasionally encountered in the HF&E and IS 'man-machine interaction' literature. Only in 1994 did *International Journal of Man-Machine Studies* become *International Journal of Human-Computer Studies*. Such differences diminished enthusiasm for building bridges and exploring literatures.

Challenges presented by regional cultures merit a study of their own. The presence in North America of the strong non-profit professional organizations ACM and IEEE led to developments not experienced elsewhere. Whether due to an entrepreneurial culture, a large consumer market, or other factors, the most successful software and Web applications originated in the United States and shaped the direction of research there. In Europe, the government role remained central; research favored technology use in large organizations. To protect domestic industries, some governments support propped up mainframe companies longer than their U.S. counterparts and discouraged imports of new U.S. technologies. The convergence and divergence of North American and European CSCW factions illustrates how the resulting differences in perspective can impede co-mingling. HCI research in Japan followed the United States emphasis on the consumer market. After focusing on methods to design and develop Japanese-language individual productivity tools, for the domestic market, on computers oriented toward English, much research turned to language-independent communication tools for the international market (Tomoo Inoue, personal communication, March 2012).

Interdisciplinarity and multicultural exploration are intellectually seductive. Could we not learn by looking over fences? But another metaphor is the Big Bang. Digital technology is exploding, streaming matter and energy in every direction, forming worlds that at some later date might discover one another and find ways to communicate, and then again, might not.

LOOKING FORWARD: TRAJECTORIES

The future of HCI will be dynamic and full of surprises. The supralinear growth of hardware capability confounds efforts at prediction—we rarely experience supralinear exponential change and do not reason well about it. In the United States, NSF is tasked with envisioning the future and providing resources to take us there, yet two major recent HCI initiatives, 'Science of Design' and 'CreativIT' (focused on creativity), were short-lived. Nevertheless, extrapolations from observations about the past and present suggest possible developments, providing a prism through which to view other work and perhaps some guidance in planning a career.

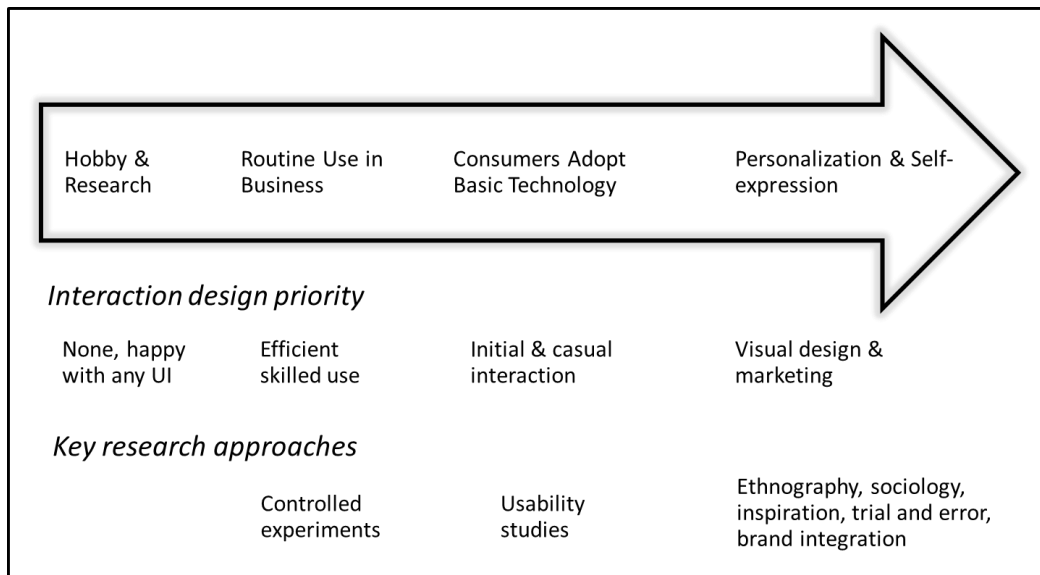


Figure 3. From invention to maturity.

The Optional Becomes Conventional

We exercise prerogative when we use digital technology—sometimes. More often when at home, less often at work. Sometimes we have no choice, as when confronted by a telephone answering system. Those who are young and healthy have more choices than those constrained by injury or aging.

Many technologies follow the maturation path shown in Figure 3. Software that was discretionary yesterday is indispensable today. Collaboration forces us to adopt shared conventions. Consider a hypothetical team that has worked together for 20 years. In 1990, members exchanged printed documents. One person still used a typewriter, whereas others used different word processors. One emphasized words by underlining, another by italicizing, and a third by bolding. In 2000, the group decided to exchange digital documents. They had to adopt the same word processor. Choice was curtailed; it was only exercised collectively. Today, this team is happy sharing documents in PDF format, so they can again use different word processors. Perhaps tomorrow software will let them personalize their view of a single underlying document, so one person can again use and see in italics what another sees as bold or underlined.

Shackel (1997, p. 981) noted this progression under the heading “From Systems Design to Interface Usability and Back Again.” Early designers focused at the system level; operators had to cope. When the PC merged the roles of operator, output user, and program provider, the focus shifted to the human interface and choice. Then individual users again became components in fully networked organizational systems. Discretion can evaporate when a technology becomes mission-critical, as word processing and email did in the 1990s.

The converse also occurs. Discretion increases when employees can download free software, bring smartphones to work, and demand capabilities that they enjoy at home. Managers are less likely to mandate the use of a technology that they use and find burdensome. For example, language understanding systems appealed to military officers—until they themselves became hands-on users:

Our military users... generally flatly refuse to use any system that requires speech recognition... Over and over and over again, we were told ‘If we have to use speech, we will not take it. I don’t even want to waste my time talking to you if it requires speech.’ ... I have seen generals come out of using, trying to use one of the speech-enabled systems looking really whipped. One really sad puppy, he said ‘OK, what’s your system like, do I have to use speech?’ He looked at me plaintively. And when I said ‘No,’ his face lit up, and he got so happy.” (Forbus, 2003; see also Forbus, Usher & Chapman, et al., 2003.)

In domains where specialized applications become essential and where security concerns curtail openness, discretion can recede. But Moore’s law (broadly construed), competition, and the ease of sharing bits should guarantee a steady flow of experimental technologies with unanticipated and thus initially discretionary uses.

Ubiquitous Computing, Invisible HCI?

Norman (1988, p. 185) wrote of “the invisible computer of the future.” Like motors, he speculated, computers would be present everywhere and visible nowhere. We interact with clocks, refrigerators, and cars. Each has a motor, but who studies human–motor interaction? Marc Weiser subsequently introduced a similar concept, ‘ubiquitous compu-

ting.' A decade later, at the height of the Y2K crisis and the Internet bubble, computers were more visible than ever. But after a quarter century, while we may always want a large display or two, would anyone call a smartphone or a book reader a computer? The visions of Norman and Weiser may be materializing.

With digital technology embedded everywhere, concern with interaction is everywhere. HCI may become invisible through omnipresence. As interaction with digital technology becomes part of everyone's research, the three long-standing HCI fields are losing participation.

Human Factors and Ergonomics. David Meister, author of *The History of Human Factors and Ergonomics* (1999), stresses the continuity of HF&E in the face of technology change:

Outside of a few significant events, like the organization of HFS in 1957 or the publication of Proceedings of the annual meetings in 1972, there are no seminal occurrences . . . no sharp discontinuities that are memorable. A scientific discipline like HF has only an intellectual history; one would hope to find major paradigm changes in orientation toward our human performance phenomena, but there is none, largely because the emergence of HF did not involve major changes from pre-World War II applied psychology. In an intellectual history, one has to look for major changes in thinking, and I have not been able to discover any in HF. (e-mail, September 7, 2004)

Membership in the Computer Systems Technical Group has declined. Technology is heavily stressed in technical groups such as Cognitive Engineering and Decision Making, Communication, Human Performance Modeling, Internet, System Development, and Virtual Environment. Nor do Aging, Medical Systems, or other groups avoid 'invisible computers.'

Information Systems. While IS thrived during the Y2K crisis and the Internet bubble, other management disciplines—finance, marketing, operations research, and organizational behavior—became more technically savvy. When the bubble burst and enrollments declined, the IS niche became less well-defined. The research issues remain significant, but this cuts two ways. As IT organizations standardize on products and outsource IT functions, more IT attention is focused on business-to-business and Web portals for customers. These raise finance and marketing considerations, which in turn leads to HCI functions migrating to other management disciplines.

Computer–Human Interaction. This nomadic group started in psychology, then won a grudgingly-bestowed seat at the computer science table. Several senior CHI people moved to information schools. Lacking a well-defined academic niche, CHI ties its identity to the SIGCHI organization and the CHI conference. Membership in SIGCHI peaked in 1992 and conference attendance peaked in 2001. As new technologies become widely used, thriving specialized conferences are formed, often started by younger researchers. World Wide Web conferences included papers on HCI issues from the outset. HCI is an 'invisible' presence in conferences on agents, design, and computing that is ubiquitous, pervasive, accessible, social and sustainable. High rejection rates for conference submissions and a new generational divide could accelerate the dispersion of research.

CHI attendance has become more exclusively academic, despite industry's need for basic research in specific areas. Apart from education and health, which have broad appeal, and software design and development, CHI remains largely focused on general phenomena and resistant to domain-specific work. This creates additional opportunities for regional and specialized conferences.

Information

Early in the computer era, there were no networks and memory was fantastically expensive. Computers were for computation, not information processing. Today, the situation is reversed: Memory and bandwidth are so plentiful that most computation is in the service of processing and distributing information. And the shift to an emphasis on information, with computation present but less visible, could well accelerate.

Cronin (2005) proposed that information access, in terms of intellectual, physical, social, economic, and spatial/temporal factors, is the focus of the information field. Information is acquired from sensors and human input, it flows over networks including the Web, and is aggregated, organized, and transformed. The routing and management of information within enterprises, as well as the consequences of ever-more-permeable organizational boundaries, is evolving. Approaches to personal information management are also rapidly changing. We once contended with shoeboxes of photographs and boxes of old papers; now many of us must make significant online information management decisions, choosing what to keep locally, what to maintain in the cloud, and how to organize it to insure its future accessibility. CHI has over a decade of work on information design and visualization.

In speculating about the future, Cronin (1995, p. 56) quotes Wersig (1992) who argued that concepts around information might function "like magnets or attractors, sucking the focus-oriented materials out of the disciplines and restructuring them within the information scientific framework." Could this happen? Information schools have hired senior and junior people from many relevant areas. Andrew Dillon, dean of the University of Texas School of Information, worked at Loughborough with Brian Shackel and Ken Eason. Syracuse, the first extant school of information (since 1974), has faculty with IS training and orientation. CHI faculty have migrated to information schools and de-

partments of several leading universities.

Communication studies is a discipline to watch. Rooted in humanities and social sciences, it is gradually assuming a quantitative focus. Centered in studies of television and other mass media, the field blossomed in the 1980s and 1990s. Only in the last several years has computer-mediated communication reached the scale of significance of the other media. HCI is in a position to draw on past work in communication as communication focuses more on digital media.

The rise of specialized programs—biomedical informatics, social informatics, community informatics, and information and communication technology for development (ICT4D)—could work against the consolidation of information studies. Information, like HCI, could become invisible through ubiquity. The annual Information Conference is a barometer. In 2005 and 2006, the halls echoed with active discussions and disagreement about directions. Should new journals and research conferences be pursued, or should researchers stick with the established venues in the various contributing disciplines? In the years since, faculty from the different fields worked out pidgin languages in order to communicate with each other. Assistant professors were hired and graduate students enlisted whose initial jobs and primary identities are with 'Information.' Will they creolize the pidgin language?

One can get a sense that the generals may still be arguing over directions, but the troops are starting to march. It is not clear where they will go. The generals are reluctant to turn over command to less busy and more fluent junior officers. The iConference has grown but vies with the less international although more established ASIST conference. However this evolves, in the long term Information is likely to be the major player in human–computer interaction. Design and Information are active HCI foci today, but the attention to design is compensating for past neglect. Information is being reinvented.

CONCLUSION: THE NEXT GENERATION

Looking back, cyclic patterns and cumulative influences are evident. New waves of hardware enable different ways to support the same activities. Email arrived as an informal communication medium, was embraced by students, regarded with suspicion by organizations, and eventually became more formal and used everywhere. Then texting and instant messaging came along as an informal medium, were embraced by students, regarded with suspicion by organizations, and eventually became used everywhere. Social networking came along...

Mindful of Edgar Fiedler's admonition that "he who lives by the crystal ball soon learns to eat ground glass," consider this: In the mid-1980s, the mainframe market lost the spotlight. Organizations were buying hundreds of PCs, but these were weak devices with little memory, hard to network. They didn't need more mainframes, but what about a massive, parallel supercomputer? Government and industry invested vast sums in high performance computing, only to discover that it was hard to decompose most computational problems into parallel processes whose output could be reassembled. As these expensive and largely ineffective efforts proceeded, PCs slowly got stronger, added some memory, got networked together, and without vast expenditures and almost unnoticed at first, the Internet and the Web emerged.

Today the desktop computer has lost the spotlight to portable devices, but it won't stop there. Organizations buy hundreds of embedded systems, sensors and effectors, but these are weak devices with little memory, hard to network. Some tasks can be handed off to a second processor, but how far can parallel multicore computers take us? Government and industry are investing large sums in parallel computing. They are rediscovering the limitations. Sensors and effectors will add processing and memory, harvest energy, and get networked. What will that lead to? The desktop computer may become a personal control station with large displays enabling us to monitor vast quantities of information on anything of interest—work and professional, family and health, the state of household appliances, Internet activity, and so forth—with a work area that supports exchanging tasks and objects with portable or distributed devices.

New technologies capture our attention, but of equal importance is the rapid maturation of technologies such as digital video and document repositories, as well as the complex specialization occurring in virtually all domains of application. Different patterns of use emerge in different cultures, different industries. Accessibility and sustainability are wide-open, specialized research and development areas. Tuning technologies for specific settings can bring human factors approaches to the fore, designing for efficient heavy use could revive command-driven interfaces, whether the commands are typed, spoken, or gestural.

Digital technology has inexorably increased the visibility of activity. We see people behaving not as we thought they would or as we think they should. Rules, conventions, policies, regulations, and laws are not consistently followed; sanctions for violating them are not uniformly applied. Privacy and our evolving attitudes toward it are a small piece of this powerful progression. Choosing how to approach these complex and intensifying challenges as individuals, families, organizations, and societies—Should or could we create more nuanced rules? When do we increase enforcement or tolerate deviance?—will be a perpetual preoccupation as technology exposes the world as it is.

Until well after it is revoked, Moore's law broadly construed will ensure that digital landscapes provide new forms

of interaction to explore and new practices to improve. The first generation of computer researchers, designers, and users grew up without computers. The generation that followed used computers as students, entered workplaces, and changed the way technology was used. Now a generation has grown up with computers, game consoles, and cell phones. They absorbed an aesthetic of technology design and communicate by messaging. They are developing skills at searching, browsing, assessing, and synthesizing information. They use smartphones, acquire multimedia authoring talent, and embrace social networking sites. They have different takes on privacy and multitasking. They are entering workplaces, and everything will be changed once again. However it is defined and wherever it is studied, human-computer interaction will for some time be in its early days.

APPENDIX: PERSONAL OBSERVATIONS

My career from 1973 to 1993 followed a common enough path. I was one of many who worked as a computer programmer, studied cognitive psychology, spent time as an HCI professional in industry, and then moved to academia. I describe personal experiences here not because I am special, but to add texture and a sense of the human impact of some of the developments I have described. My interest in history arose from the feeling of being swept along by invisible forces, sometimes against my intention. My first effort at understanding was titled "The Computer Reaches Out" (Grudin, 1990) because I saw computers evolving and slowly reaching into the world and changing it in ways that we, their developers, had not foreseen.

1970: A Change in Plans. As a student, I read and believed the Life magazine article that forecasted computers with super-human intelligence arriving in several years. I concluded that if we survived a few years, we could count on machines to do all useful work. Human beings should focus on doing what they enjoy. I shifted from physics to mathematics and from politics to literature.

1973: Three Professions. Looking for my first job in 1973, I found three computer job categories in the Boston Globe classified: (1) operators, (2) programmers, and (3) systems analysts. Not qualified to be a highly paid analyst, I considered low-paid, hands-on operator jobs but I landed a programming job with Wang Laboratories, which was at the time a small electronics company. For two years, I never saw the computer that my programs ran on. I flowcharted on paper and coded on coding sheets that a secretary sent to be punched and verified. A van carried the stack of cards 20 miles to a computer center, and later that day or the next day I got the printout. It might say something like "Error in Line 20," and I would resume work on the program.

1975: A Cadre of Discretionary Hand-On Users. In 1975, Wang acquired a few teletype terminals with access to the WYLBUR line editor, developed at the Stanford Linear Accelerator. Some of us programmers chose to abandon paper and became hands-on computer users.

1983: Chilly Reception for a Paper on Discretion in Use. My first HCI publication, Grudin & MacLean (1984), was written when I was a postdoc at the MRC Applied Psychology Unit. Allan and I showed that people sometimes choose a slower interface for aesthetic or other reasons even when they are familiar with a more efficient alternative. A senior colleague asked us not to publish it. He worked on improving expert efficiency through cognitive modeling. A demonstration that greater efficiency could be undesirable would be a distraction, he said: "Sometimes the larger enterprise is more important than a small study."

1984: Encountering Moore's Law, Information Systems, Human Factors, and Design. I returned to Wang, which had become a large minicomputer company, and found that Moore's law had changed the business. Hardware was now often ordered from catalogs and the reduced cost of memory contributed to changing the priorities and skills of programming. I was soon influenced by another cognitive psychologist, Susan Ehrlich, who worked in a marketing research group and later managed the human factors group. She introduced me to the IS literature, which I found difficult to understand. I attended Boston-area chapter meetings of both HFS and SIGCHI. I saw the cultural differences but felt CHI could learn from human factors. In a futile gesture to counter CHI antipathy toward human factors, I began calling myself a human factors engineer. I drove to Cambridge to see the newly released Macintosh. Few software engineers had the visual design skills that I realized would become important, so at work I looked for industrial designers of hardware ('boxes') who could be enlisted to support software interface design.

1985: The GUI Shock. In the early 1980s, Phil Barnard and I were among the many cognitive psychologists working on command naming. This was an important application in the era of command-line interfaces, but the ambition was to develop a comprehensive theoretical foundation for HCI. The success of the Mac in 1985 curtailed interest in command

names. No one would build on our past work—a depressing thought. It also dashed the hope for a comprehensive theoretical foundation for HCI. We had to choose: Am I a cognitive psychologist or a computer professional? Phil remained a psychologist.

1986: Beyond “The User”: Groups and Organizations. I agreed to join MCC, an industry research consortium. Between jobs I worked on two papers, each addressing a major challenge encountered in product development. (i) From 1984 to 1986, I had worked on several products or features intended to support groups rather than individual users. These had not done well. Why was group support so challenging? (ii) It was painfully evident that organizational structures and development processes were badly suited to interactive software development. What could be done about it? These issues formed the basis for much of my subsequent research.

1989: Development Contexts: A Major Differentiator. I spent two years at Aarhus University. Within weeks of arriving in a country that had little commercial software development, I saw that differences in the conditions that govern product, in-house, and contract development of interactive software, could shape practices and perceptions in CHI, IS, and software engineering. Sorting this out led to my first library research for purely historical purposes (Grudin, 1991). Perusing long-forgotten journals and magazines in dusty library corridors felt like wandering through an archaeological site.

1990: Just Words: Terminology Can Matter. I felt a premonition in 1987 when my IS-oriented colleague Susan Ehrlich titled a paper “Successful Implementation of Office Communication Systems.” By implementation, she meant introduction into organizations. To me, implementation was a synonym for coding or development. Sure enough, the ACM editor asked her to change the word ‘implementation’ to ‘adoption’ (Ehrlich, 1987). What she called systems, I called applications. Was language, usually an ally, getting in the way?

In 1990, I describe the focus of my planned HCI course at Aarhus as “user-interface evaluation.” My new colleagues seemed embarrassed. Weeks later, a book written by one of them was published (Bødker, 1990). Its first sentence was a quotation: “Design is where the action is, not evaluation.” Now I was embarrassed. In an in-house development world, with its dogma of getting the design right up front, development projects could take ten years. Evaluation occurred at the end, when only cosmetic changes were possible, and had a negative stigma. In commercial product development, evaluation of the previous version, competitive products, and (ideally) prototypes was integral to design. Evaluation is central to iterative design. It draws on the experimental psychologist’s skillset. We considered it a good thing.

Later in 1990, I participated in a panel on task analysis at a European conference. To my dismay, this IS-oriented group defined task analysis differently than I did. To them, it meant an organizational task analysis: tasks as components in a broad work process. In CHI, it meant a cognitive task analysis: breaking a simple task into components; for example, is “move text” thought of as ‘select-delete-paste’ or as ‘select-move-place’? Some Europeans felt that North American claims to have conducted task analyses were disgraceful, not understanding this context.

Also in 1990, en route to giving a job talk at UC Irvine, my first lecture to an IS audience at the UCLA Anderson School of Management ended badly when the department head asked a question. It seemed meaningless, so I replied cautiously. He rephrased the question. I rephrased my response. He started again, then stopped and shrugged as if to say, “This fellow is hopeless.” When I saw him a few months later, he seemed astonished to learn that his Irvine friends were hiring me. Later, I understood the basis of our failure to communicate: We attached different meanings to the word ‘users.’ To me, it meant hands-on computer users. He was asking about IS users who specified database requirements and read reports, but were not hands-on computer users. To CHI researchers, all use was hands on, so his question had made no sense to me.

A book could be written about the word ‘user.’ From a CHI perspective, the IS user was the ‘customer.’ Consultants use ‘client.’ In IS, the hands-on user was the ‘end-user.’ In CHI’s parlance, ‘end-user’ and ‘user’ were one and the same—a person who entered data and used the output. The word ‘end-user’ seemed superfluous or an affectation. Human factors used ‘operator,’ which CHI considered demeaning. In software engineering, ‘user’ typically denoted a tool user, which is to say a software engineer.

A final terminology note: the male generic. I avoided submitting to *International Journal of Man-Machine Studies* and turned down an invitation to speak at a ‘man-machine’ interaction event. I was keen on learning from other disciplines, but that was a linguistic bridge I tried to avoid crossing. I generally consider words to be a necessary but uninteresting medium for conveying meaning, but such experiences led to an essay on unintended consequences of language (Grudin, 1993).

2005: Considering HCI history. My intermittent efforts to understand the past came together in a short article published in 2005 in *IEEE Annals of the History of Computing*. CHI and the HCI journals didn’t include history in their scope, but *ACM Interactions* magazine then solicited a column or forum which I’ve edited since, collecting essays from people with different perspectives and interests, and writing some myself. Two favorites are Glenn Kowack’s January 2008 essay on the evolution of the Internet and my May 2008 essay on the design methods of Henry Ford and Howard Hughes.

2012: *Reflections on Bridging Efforts*. I've been a minor participant in efforts to find synergies across CHI and (i) human factors, (ii) office information systems, (iii) information systems (in CSCW and in AIS SIGHCI), and (iv) Design. None succeeded. In interviews, people who long ago participated in multiple areas before withdrawing into one identified obstacles described in this essay. I encountered several myself. As a boomer, I experienced generational and cultural divides. Many of my MCC colleagues joined the consortium to avoid 'Star Wars' military projects. We lived through disputes between cognitive psychologists and radical behaviorists. I was among the CHI researchers who shifted from journals to conferences as the primary publication venue, and from hypothesis-driven experimentation to qualitative field research or prototyping approaches.

Some differences fade over time but many persist. Reviewers are often irritated by unfamiliar acronyms used by authors from other fields. Writing a chapter for an IS-oriented book (Palen & Grudin, 2002), my coauthor and I wrangled at great length with the editor over terminology.

In researching this article, I reviewed the literature on TAM, the model of white-collar employee perceptions of technology that is heavily cited in IS but never in CHI. I unsuccessfully searched online for TAM references. Only on my third attempt did I see the problem: TAM stands for 'Technology Acceptance Model,' but I repeatedly typed in 'Technology Adoption Model.' Nondiscretionary acceptance vs. discretionary adoption: Different biases lead to different terminology, and confusion.

2012: *Predictions*. Detailed forecasts, including mine, rarely hold up well to close inspection. But understanding both the present and the forces that shaped the past offer us the best chance of anticipating or reacting quickly to future events. Equally useful is a sense of where efforts will be futile. Paradoxically, common errors are to underestimate both the immovable object that is deeply engrained human nature and the irresistible force of technology change. Perhaps in part because of our behavioral and institutional inertia, once effects start to be felt, they often escalate very rapidly. I published projections in the last 2006 and first 2007 issues of *ACM Interactions*—check to see how I'm doing. Free access to my publications is found at <http://research.microsoft.com/en-us/um/people/jgrudin/>.

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