Three Faces of Human–Computer Interaction

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Human–computer interaction is considered a core element of computer science. Yet it has not coalesced; many researchers who identify their focus as human–computer interaction reside in other fields. I examine the origins and evolution of three HCI research foci: computer operation, information systems management, and discretionary use. I describe efforts to find common ground and forces that have kept them apart.

People have interacted with computers from the start, but it took time for human–computer interaction (HCI) to become a recognized field of research. Related journals, conferences, and professional associations appeared in the 1970s and 1980s. HCI is in the curricula of research universities, primarily in computer science, yet it has not coalesced into a single discipline. Fields with researchers who identify with HCI include human factors and ergonomics, information systems, cognitive science, information science, organizational psychology, industrial engineering, and computer engineering.

This article identifies historical, conceptual, and cultural distinctions among three major research threads. One thread extended human factors or engineering psychology to computing. Another developed when mainframes spawned business computing in the 1960s. The third, focused on individual use, arose with minicomputers and home computers and burgeoned with personal computing in the 1980s.

Although they share some issues and methods, these research efforts have not converged. They emerged within different parent disciplines, at different times, and comprised different generations of researchers. Approaches, attitudes, and terminology differed. Two—computer operation and information systems management—embraced the journal-oriented scholarly tradition of the sciences; the third—comprising cognitive and computer scientists—has placed greater emphasis on conference publication. In addition, each thread initially emphasized a different aspect of computer use: mandatory hands-on use, hands-off managerial use, and discretionary hands-on use. Designing for a use that is a job requirement and designing for a use is discretionary can be very different activities. These often unvoiced distinctions contributed to the current state of HCI research and may shape its future.

Human–tool interaction at the dawn of computing

Highly specialized tools were developed through the centuries to support carpenters, blacksmiths, and other artisans. However, efforts to apply science and engineering to improve the efficiency of work practices became prominent only about a century ago, when time-and-motion studies exploited inventions such as film and statistical analysis. Frederick Taylor's principles of scientific management[1] had limitations and were satirized in Charlie Chaplin's film *Modern Times*, but they were applied successfully to assembly line manufacturing and other work practices.

World War I training requirements accelerated efficiency efforts in Europe and the US. World War II prompted intense interest in engineering psychology as a result of complex equipment used by soldiers, sailors, and pilots that tested human capabilities. Aircraft ergonomic design flaws—for example, in the ejection system's escape hatch—led to thousands of casualties. After the war, aviation psychologists created the Human Factors Society. Two legacies of World War II were awareness of the potential of computing and an enduring interest in behavioral requirements for design and training.[2]

Early approaches to improving work and what at the time were called man–machine interfaces focused on nondiscretionary use. Assembly line workers were hired to use a system; pilots were given planes—neither had a choice in the matter. If training was necessary, the workers and pilots were trained. Research goals included reducing training time, but most important was eliminating errors and increasing the pace of skilled performance.

Three roles in early computing

ENIAC, arguably the first general-purpose electronic computer in 1946, was 10 feet tall, covered 1,000 square feet, and consumed as much energy as a small town. Once a program was written, several people loaded it by setting switches, dials, and cable connections. Despite a design innovation that boosted vacuum tube reliability by enabling them to be operated at 25 percent normal power, 50 spent tubes had to be found and replaced on an average day.

Early computer projects employed people in three roles: operation, management, and programming. A small army of operators was needed. Managers oversaw design, development, and operation, including the specification of programs to be written and the distribution of results. Each role eventually became a focus of HCI research, and despite the continual evolution of computers and the activities around them, we still find that these roles reflect aspects of this early division of labor.

1945–1958: Managing vacuum tubes

Reducing operator burden was a key focus of early innovation: eliminating the need to reset vacuum tubes, facilitating replacement of burned-out tubes, and developing stored-program computers that could be loaded by tape rather than manually with cables and switches. These endeavors were consistent with the "knobs and dials" human factors tradition. By the late 1950s,[3] one computer operator could do the work that previously required a team.

The first engineers to design and build computers chose their vocations. They delegated routine tasks to human operators. As computers became more reliable and capable, programming became a central activity. People took it up because they enjoyed it. To improve programmers' interfaces to computers meant to develop languages, compilers, and constructs such as subroutines. Grace Hopper, a pioneer in these areas in the 1950s, described her goal as "freeing mathematicians to do mathematics."[4] This is echoed in today's usability goal of freeing users to do their work.

1958–1965: Transistors open new vistas

Early forecasts that the world would need few computers reflected the limitations of vacuum tubes. The arrival of commercial solid-state computers in 1958 led to dramatic change. As computers were deployed more widely, attention to the operators' job increased. Even more significantly, people could envision possibilities that were unimaginable for barn-sized machines of limited capability.

Helping operators

"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."[5]

—Brian Shackel

Low-paid computer operators set switches, pushed buttons, read lights, loaded and burst printer paper; they loaded and unloaded cards, magnetic tapes, and paper tapes, and so on. Teletypes were the first versatile mode of direct interaction. Operators typed commands and read printed computer responses and status messages on paper that scrolled up one line at a time. The first displays (called VDUs or VDTs for visual display units or terminals, or CRTs for cathode ray tubes) were nicknamed *glass ttys*—glass teletypes—because they too scrolled up operator commands and computer-generated messages. Most displays were monochrome and restricted to alphanumeric characters. Early terminals cost around $50,000 in today's dollars: expensive, but a small fraction of the cost of a computer. A large computer might have one console, used only by the operator.

Improving the design of console buttons, switches, and displays was a natural extension of human factors. Experts in this field authored the first human–computer interaction papers, capturing the attention of some who were developing and acquiring systems in industry and government. In 1959, Brian Shackel published the article, "Ergonomics for a Computer,"[6] followed by "Ergonomics in the Design of a Large Digital Computer Console."[6] Sid Smith published "Man–Computer Information Transfer" in 1963.[6]

Early visions and demonstrations

In his influential 1945 essay "As We May Think," Vannevar Bush, who helped shape scientific research funding in the US, described a mechanical device that anticipated many capabilities of computers.[7] After transistors replaced vacuum tubes, a wave of creative writing and prototype building by several computer pioneers and experts led to expanded and more realistic visions.

J.C.R. Licklider outlined requirements for interactive systems and accurately predicted which would prove easier (for example, visual displays) and which more difficult (for example, natural-language understanding). John McCarthy and Christopher Strachey proposed time-sharing systems, crucial to the spread of interactive computing. In 1963, Ivan Sutherland's Sketchpad demonstrated constraints, iconic representations, copying, moving, and deleting of hierarchically organized objects, and object-oriented programming concepts. Douglas Engelbart's broad vision included the foundations of word processing, invention of the mouse and other input devices, and an astonishing public demonstration of distributed computing that integrated text, graphics, and video. Ted Nelson anticipated a highly interconnected network of digital objects, foreshadowing aspects of Web, blog, and wiki technologies. Rounding out this period were Alan Kay's descriptions of personal computing based on versatile digital notebooks.[8]

Progress in HCI is perhaps best understood in terms of inspiring visions and prototypes, widespread practices, and the relentless hardware advances that enabled software developers to transform the former (visions and prototypes) into the latter. Some of the anticipated capabilities are now taken for granted, some are just being realized—others remain elusive.

Titles such as "Man–Computer Symbiosis," "Augmenting Human Intellect," and "A Conceptual Framework for Man–Machine Everything" described a world that did not exist, in which people who were not computer professionals were hands-on users of computers out of choice. The reality was that for some time to come, most hands-on use would be routine, nondiscretionary operation.

Discretion in computer use

Our lives are distributed along a continuum between the assembly line nightmare of *Modern Times* and utopian visions of completely empowered individuals. To use a technology or not to use it: Sometimes we have a choice, other times we don't. When I need an answer by phone, I may have to wrestle with speech recognition and routing systems. In contrast, my home computer use is largely discretionary. The workplace often lies in-between: Technologies are recommended or prescribed, but we ignore some injunctions, obtain exceptions, use some features but not others, and join with colleagues to advocate changes in policy or availability.

For early computer builders, their work was more a calling than a job, but operation required a staff to carry out essential but less interesting repetitive tasks. For the first half of the computing era, most hands-on use was by people hired with this 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 exercised more choice in what they did with computers and how they did it. Rising expectations played a role—people have learned that software is flexible and expect it to be more congenial. Competition among vendors produces alternatives. Today, more use is discretionary, with more emphasis on marketing to consumers and stressing user-friendliness.

Discretion is not all-or-none. No one must use a computer. But many jobs and pastimes require it. True, people can resist, sabotage, use some features but not others, or quit the job. But a clerk or systems administrator is in a different situation than someone using technology for leisure activity. For an airline reservation operator, computer use is mandatory. For someone booking a flight, use is discretionary. This article explores implications of these differences.

Several observers have remarked on the shift toward greater discretion. A quarter century ago, John Bennett predicted that discretionary use would lead to more concern for usability.[9] A decade later, Liam Bannon noted broader implications of a shift "from human factors to human actors."[10] But the trajectory is not always toward choice. Discretion can be curtailed even as more work is conducted digitally—for example, a word processor is virtually required, no longer an alternative to 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 diverse HCI efforts: the early and ongoing human factors work, visionary writers and prototype builders, systems management, performance modeling, the relentless pursuit of some technologies despite limited marketplace success, the focus of government research funding, the growing emphasis on design, and unsuccessful efforts to bridge research fields.

1965–1980: HCI before personal computing

In 1964, Control Data Corp. launched the transistor-based 6000 series. In 1965, integrated circuits arrived with the IBM System/360. These powerful computers, later christened *mainframes* to distinguish them from minicomputers, brought computing into the business realm. At that point, each of the three roles in computing—operation, management, programming—became a significant profession.

Operators interacted directly with computers for routine maintenance, loading and running programs, filing printouts, and so on. This hands-on category can be expanded to include data entry, retrieval, and other repetitive tasks necessary to feed the computer.

Managers variously oversaw hardware acquisition, software development, operation, and routing and using output. They were usually not hands-on users.

Programmers were rarely direct users until late in this period. Instead, they flowcharted programs and wrote them on paper. Keypunch operators then punched the program instructions onto cards. These were sent to computer centers for computer operators to run. Printouts and other output were picked up later. Many programmers would use computers directly when they could, but the cost of computer use generally dictated an efficient division of labor.

Human factors and ergonomics

In 1970, Brian Shackel founded the Human Sciences and Advanced Technology (HUSAT) center at Loughborough University in the UK, devoted to ergonomics research emphasizing HCI. Sid Smith and other human factors engineers published through this period.[11] In 1972, the Computer Systems Technical Group (CSTG) of the Human Factors Society formed, and soon it was the largest technical group in the society.

Leading publications were the general journal *Human Factors* and the computer-focused *International Journal of Man-Machine Studies* (*IJMMS*), first published in 1969.

The first influential HCI book was James Martin's 1973 *Design of Man–Computer Dialogues*.[12] A comprehensive survey of interfaces for operation and data entry, it began with an arresting opening chapter describing a world in transition. Extrapolating from declining hardware prices, Martin 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.[12]

In 1980, two major HCI books on VDT design and one on general ergonomic guidelines were published.[13] German work on VDT standards, first published in 1981, provided an economic incentive to design for human capabilities by threatening to prohibit noncompliant products.

Information systems

Beginning in 1967, the journal *Management Science* published a column titled "Information Systems in Management Science." Early definitions of IS[14] 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." A historical survey of IS research identifies HCI as one of five major research streams, initiated by Russell Ackoff's 1967 paper on challenges in dealing with computer-generated information.[15]

Companies acquired expensive business computers to address major organizational concerns. Managers could be virtually chained to them almost as tightly as Shackel's operator and data entry "slaves." However, operator or end-user resistance to using a system could be a major management concern. For example, the sociotechnical approach involved educating representative workers in technology possibilities and involving them in design to increase acceptance of the resulting system.[16]

Cognitive style, a major topic of early IS research, focused on difficulties that managers had communicating with people knowledgeable about computers. IS researchers published in management journals and in the human-factors-oriented *IJMMS*.[17]

Programming: Subject of study, source of change

In the 1960s and 1970s, more than 1,000 research papers on variables affecting programming performance were published. Most viewed programming in isolation, independent of organizational context. Gerald Weinberg's landmark *The Psychology of Computer Programming* appeared in 1971. In 1980, Ben Shneiderman published *Software Psychology,* and Beau Sheil reviewed studies of programming notation (conditionals, control flow, data types), practices (flowcharting, indenting, variable naming, commenting), and tasks (learning, coding, debugging).[18]

Programmers changed their own 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 drew researchers and system builders from the labs of Engelbart and Sutherland. In 1971, Allen Newell of Carnegie Mellon University proposed a project to PARC, 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)."[19]

Like HUSAT, also launched in 1970, PARC had a broad research 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 and a few other places extended human factors to higher-level cognition. HUSAT, influenced by sociotechnical design, extended human factors by considering organizational factors.

1980–1985: Discretionary use comes into focus

In 1980, Human Factors and Ergonomics (HF&E) and IS were focused more on improving efficiency than on augmenting human intellect. In contrast, many programmers were captivated by this promise of computation. Growing numbers of students and hobbyists used minicomputers and microprocessor-based home computers, creating a population of hands-on discretionary users. Twenty years later, the visions early pioneers had of people choosing to use computers that helped them work better began to come true. And as a result, the cognition of discretionary users became a topic of interest.

Human Interaction with Computers, a 1980 book by Harold Smith and Thomas Green, perched on the cusp. It briefly addressed "the human as a systems component" (the nondiscretionary perspective). One-third covered research on programming. The remainder addressed "non-specialist people," discretionary users who were not computer specialists. Smith and Green wrote: "It's not enough just to establish what people can and cannot do; we need to spend just as much effort establishing what people can *and want to do*." [Italics in the original.][20]

The formation of ACM SIGCHI

In 1980, as IBM prepared to launch the PC, a groundswell of attention to computer user behavior was building. IBM had recently added software to hardware as a product focus.[21] Several cognitive psychologists joined an IBM research group that included John Gould, who had engaged in human factors research since the late 1960s. They initiated empirical studies of programming and software design and use. Other psychologists who led recently formed HCI groups included Phil Barnard at the Medical Research Council Applied Psychology Unit (APU); Tom Landauer at Bell Labs; Donald Norman at the University of California, San Diego; and John Whiteside at Digital Equipment Corp.

PARC and CMU were particularly influential. In 1980, Stuart Card, Thomas Moran, and Allen Newell published "Keystroke-Level Model for User Performance Time with Interactive Systems" and introduced cognitive elements as components of the goals, operators, methods, selection rules (GOMS) model that was the basis for their landmark 1983 book, *The Psychology of Human–Computer Interaction*.[22]

Communications of the ACM initiated the "Human Aspects of Computing" department in 1980. *Computing Surveys* published a special issue on "The Psychology of the Computer User" the next year, edited by Tom Moran. The Association for Computing Machinery (ACM) Special Interest Group on Social and Behavioral Science Computing (SIGSOC) extended its 1981 workshop to cover interactive software design and use; the group shifted to the latter focus and adopted the name Computer–Human Interaction (SIGCHI) in 1982.

In 1983, the first CHI conference[23] drew more than 1,000 people. Cognitive psychologists in industry dominated the program. Half of the 58 papers were from the seven organizations mentioned earlier. The 1983 Computer–Human Interaction Conference (CHI 83) was cosponsored by the Human Factors Society. Human factors contributors included program chair Richard Pew, committee members Sid Smith, H. Rudy Ramsay, and Paul Green, and several presenters. Brian Shackel and society president Robert Williges gave tutorials the first day. "Human Factors in Computing Systems" was and remains the conference subtitle.

CHI and human factors diverge

Despite the initial interdisciplinary cooperation with human factors specialists, most cognitive psychologists were familiar with interactive software but not the human factors research literature. Many had turned to HCI after earning their degrees, when academic psychology positions became scarce. The Human Factors Society did not again cosponsor CHI, and its researchers disappeared from the CHI program committee. Soon, few CHI authors identified themselves with human factors.

Reservations about human factors were evident in *The Psychology of Human–Computer Interaction*:

> 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 …[22]

Two years later, Newell and Card noted that human factors had a role in design but

> 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.[24]

In a June 2004 email communication, Card said "Human factors was the discipline we were trying to improve," and

> 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.

"Hard science, in the form of engineering, drives out soft science, in the form of human factors," wrote Newell and Card.[24] "Cognitive engineering" and "usability engineering" appeared; human factors disappeared. Most CHI researchers who had published in the annual human factors conference and *Human Factors* shifted to CHI, *Communications of the ACM*, and the journal *Human–Computer Interaction* established in 1985 by Tom Moran.

In the first paper presented at CHI 83, "Design Principles for Human–Computer Interfaces," Donald Norman experimented with applying engineering techniques to discretionary use, creating "user satisfaction functions" based on technical parameters.[25] Only slowly would CHI stop identifying so strongly with engineering.

Although highly respected, human performance modeling did not draw a large CHI following. Key goals of the modelers differed from those of practitioners and other researchers. "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."[26] This helps design for nondiscretionary users, such as telephone operators engaged in repetitive tasks.[27] But CHI focused instead more on the first experiences of new discretionary users: The early vision was, two decades later, a pressing concern for software and telecommunications companies.

The shift was reflected at IBM T.J. Watson Research Center. John Gould and Clayton Lewis authored a CHI 83 paper that beautifully defined the CHI focus on user-centered, iterative design based on prototyping,[28] and Watson cognitive scientists helped shape CHI. But Gould's principal focus remained human factors; he served as Human Factors Society president in 1987–1988. Symbolically, in 1984 Watson's Human Factors Group faded away and a User Interface Institute emerged.

Ruven Brooks, Bill Curtis, Thomas Green, Ben Shneiderman, and other CHI founders continued the psychology-of-programming research thread. Watson researchers also contributed, I learned from John Thomas in an Oct. 2003 email:

> 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 "non-programmers" to be able, essentially, to program.

Line editors displaced coding sheets, and programming became the first profession populated by discretionary computer users. Many studies of programmers as new hands-on users were published in the early conferences. In 1984 at an INTERACT session I attended, Thomas Green remarked that "text editors are the white rats of HCI." As personal computing spread and the same methods were applied to studying other discretionary use, studies of programming gradually disappeared.

CHI focused on novice use for several reasons. Initial experience is particularly important for discretionary users, and thus for the many vendors who sprang up to develop software for PCs, workstations, and minicomputers. Novices are a natural focus when studying new technologies that have few experts. And initial use is critical when more people take up computing each year than did the year before.

Routine or experienced computer use was widespread in this period. Computer databases were extensively used by airlines, banks, government agencies, and other organizations. But hands-on activity was rarely discretionary. Managers oversaw development and read reports, leaving data entry and information retrieval to people hired for those jobs. CHI studies of database use were few—I count three over a decade, all focused on novice or casual use. Improving skilled data entry was a human factors undertaking.

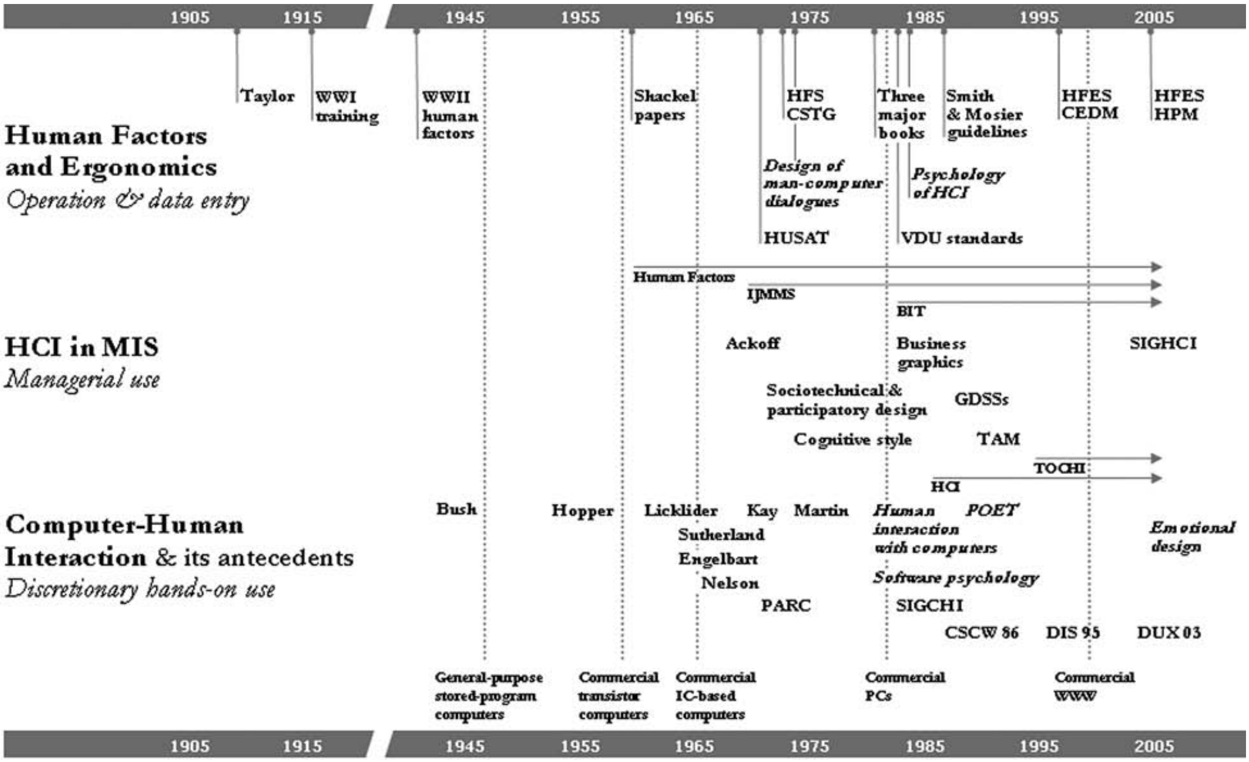

Figure 1. Timeline for some events, topics, and publications discussed in the text.

With fewer European companies producing mass-market software, research remained more focused on less discretionary in-house development and use. 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 International Conference on Human–Computer Interaction (INTERACT) conference, first held in London in 1984 and chaired by Shackel, drew HF&E and CHI researchers.

In a perceptive essay written later from a European perspective, Bannon urged that more attention be paid to discretionary use, while also criticizing the exclusive focus on initial experiences that marked CHI.[10]

Figure 1 positions some HCI events and topics on a timeline. The top row represents the Human Factors and Ergonomics, predominantly nondiscretionary, HCI focus. In the center is HCI in MIS (or Information Systems), initially focused on use that was relatively nondiscretionary and hands-off. At the bottom are CHI and its logical antecedents as discretionary use shifted from engineers to programmers to other individuals and groups.[29]

James Martin's comprehensive 1973 guide to designing for data entry and retrieval belongs in the top row, although his farsighted introduction, describing a future in which users are in control, places him among those who anticipated discretionary use in the bottom row. *The Psychology of Human–Computer Interaction,* which introduced cognitive modeling, is placed at the top despite being the work of CHI researchers, because it focused on expert performance and the reform of human factors. Discretion was not in its scope. A leading modeler discouraged publication of a 1984 study of a repetitive task that showed people preferred a pleasant but slower interaction technique—a result significant for discretionary use, but not for modeling aimed at maximizing performance.[30]

The visionaries were not well-known within CHI in 1983. The 633 references in the 58 papers presented at CHI 83 included many authored by well-known cognitive scientists, but Bush, Engelbart, and Sutherland were not cited at all. Shared concern for discretionary use, conceptual continuity, and the legitimacy bestowed by a luminous past led CHI to graft these pioneers onto CHI history somewhat after the fact.

1985–2005: New interfaces, Internet, and the Web

Human–computer interaction in the personal computing era has been marked by the spread of Internet and intranet use, graphical user interfaces, and the World Wide Web. Although Internet users doubled annually with remarkable regularity, it required decades to become a significant fraction of the population.

Graphics made hard-earned progress through the 1960s and 1970s. In 1981, the Xerox Star was the first product with a full GUI. The Star, the Apple Lisa, and other early GUIs did not do well. When the 1984 Macintosh failed with corporate buyers, Apple's survival was uncertain. Late in 1985, positive consumer response and niche use for graphics and desktop publishing validated the Mac and the GUI.[31] When the Web linked the nodes of a steadily expanding Internet, graphics were there to provide compelling content.

These breakthroughs played out differently in the three HCI research domains. The Macintosh appeal to discretionary users had an immediate, sweeping impact on CHI research. GUIs did not attract significant corporate attention until Windows 3.0 succeeded in 1990, delaying the impact on HF&E and IS until the technology was better understood. CHI took the discretionary early Web activity in stride, although it raised new issues. Initially a return to a form-based interaction style, the Web interface had less impact on HF&E. For IS, the Web's discretionary appeal and economic significance brought opportunities and challenges.

HF&E and the role of government

Understanding the field of human factors and ergonomics requires a look at the role of government as user and supporter of research and development. HF&E research has responded to military, aviation, and telecommunications interests, with government often leading the way. Bureaucratic needs—census, tax, social security, health and welfare, power plant operation, air traffic control, ground control for space missions, military logistics, processing text and voice data for intelligence—contribute to government's being the largest consumer of computing.

With primarily nondiscretionary bureaucratic use, small efficiency gains in individual transactions yield large benefits over time. For routine data entry and information retrieval or complex speech recognition and natural-language understanding, incremental improvements that may not register with discretionary users make a difference.

Government drove the development of ergonomic standards. Acquiring a novel interactive system through a competitive bidding process is tricky. As customers formulate requirements, they must remain at arms' length from potential developers who know more about technical possibilities. Compliance with standards can be specified in a contract.

In 1986, Sid Smith and Jane Mosier published the last in a series of government-sponsored interface guidelines. They mentioned but did not address GUIs in 944 guidelines organized into sections titled Data Entry, Data Display, Data Transmission, Data Protection, Sequence Control, and User Guidance. GUIs would expand the design space tremendously. Interfaces came to be based on predefined styles rather than built from scratch; contracts came to specify design processes rather than adherence to specific feature guidelines.[32]

Worldwide, research funding is directed by governmental initiatives and shaped by government concerns. The result is a focus on mandatory use. The US National Science Foundation's interactive systems program—subsequently renamed Human–Computer Interaction—was described in this way:

> 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.[33]

Speech recognition and natural-language understanding, strongly emphasized by the NSF, are useful when a phone system provides no alternative, when a disability limits keyboard use, when hands are otherwise occupied, or for professional translators and intelligence analysts. But they have rarely been used by people who have much choice.

The Human Factors Society undertook a survey that indicated little overlap with CHI, where high-tech commercial vendor companies drove research into discretionary use. NSF and DARPA HCI program directors rarely attended CHI. Little on speech recognition or natural language appeared at CHI conferences. Another significant NSF focus, the use of brainwaves to drive computer displays, may also have uses but perhaps not in many homes or offices.

A review panel that included CHI members noted that NSF-funded researchers (PIs, or principal investigators) did not come from their midst:

> In reviewing HCI Program coverage we consulted the on-line HCI Bibliography (www.hcibib.org). This heavily-used (over one million searches) public index of over 24,000 records covers the full contents of 14 journals, 20 conferences, books and other materials. It lists 506 authors with ten or more publications. No PI for the 10 randomly selected FY1999-FY2002 HCI Program awards is on this list… HCI program grants are not fully reflective of the HCI literature …[34]

An official said: "NSF's logic is that it should primarily support research on difficult topics, often NOT those industry is heavily working on" (William Bainbridge, email to author, Nov. 2003). But it may be differences in priority and perceived significance, not difficulty, that distinguishes these efforts.

In the late 1990s, cognitive psychologists became more influential within the Human Factors and Ergonomics Society ("Ergonomics" was added in 1992; [HFES]). The largest technical group is now Cognitive Engineering and Decision Making ("CEDM" in Figure 1), which formed in 1996. The Human Performance Modeling technical group (HPM) was established in 2004 by Wayne Gray and CHI 83 program chair Richard Pew. The effort to reform human factors from the outside that accompanied the birth of CHI has moved within, led by some of the same people.

Starting in 1987, a biennial Human–Computer Interaction International conference series has drawn from industrial engineering, human factors, and government-contracted research and development. Despite its size—more than 1,000 papers were presented in 2003—HCII has modest visibility in the CHI community.

IS and the formation of AIS SIGHCI

GUIs did not have a major impact on IS in the 1980s, but business graphics did. Visual display of information affects everyone. HF&E had long addressed manuals and displays, software psychologists considered flowcharts and code organization, and IS focused on the presentation of quantitative data. Izak Benbasat and Albert Dexter wrote an influential paper that contrasted tables and charts and considered effects of color.[35]

IS research included the management of programming in organizations.[36] Also, sociotechnical and Scandinavian participatory approaches, initiated earlier to bring nondiscretionary users into design, gained recognition.[37]

Research into computer-supported meeting facilities flourished in the mid-1980s, assisted by declining costs of interactive computing.[38] Unlike most group support technologies commercialized in this period, they originated in IS, not software or computer companies. Their expense and managerial focus limited their mass-market appeal.

Within enterprises, discretionary use increased: Fewer employees were "almost slaves feeding the machine." Embrace of the Internet created more porous organizational boundaries. Even when productivity benefits are uncertain, employees bring consumer software such as free instant messaging (IM) clients and music players inside the firewall. Free Web-based software that enables one to create a weblog in a few minutes is a different animal than high-overhead applications of the past. In addition, home use of software reduces employee patience with poor interactive software at work. Managers who were hands-off users in the 1980s became late adopters in the 1990s, and are now hands-on early adopters of technologies that benefit them.[39]

In 1989, Fred Davis introduced the influential Technology Acceptance Model (TAM). Influenced by early CHI research, TAM identifies perceived usefulness and perceived utility as key factors in improving "white collar performance … often obstructed by users' unwillingness to accept and use available systems."[40] This managerial view is reflected in the term *acceptance*, reflecting a lack of choice. In contrast, CHI authors speak only of *adoption*.

The Web had a seismic effect in IS when e-commerce took off in the late 1990s. When the Internet bubble popped, organizations continued building portals: The Web had become an essential business tool.

IS was where CHI had been 20 years earlier: IT professionals who had previously focused on internal operations were now tasked with providing interfaces to highly discretionary external customers.

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 works by CHI researchers and made it a priority to bridge to CHI. In contrast, HF&E is not among five key disciplines that are considered; it is the last of seven "related" fields.

SIGHCI's broad charter includes a range of organizational issues, but published work focuses on interface design for e-commerce, online shopping, online behavior "especially in the Internet era," and effects of Web-based interfaces on attitudes and perceptions. Eight of 10 papers in special journal issues covered Internet and Web behavior.[41]

CHI and the shifting focus of discretionary use

CHI immediately took up issues raised by GUIs, such as mouse manipulation, visual display of information, and user interface management systems (UIMSs). An influential 1986 analysis by Edwin Hutchins, James Hollan, and Donald Norman concluded that "it is too early to tell" how GUIs would fare.[42] Concluding that GUIs could well prove useful for novices, the authors said "we would not be surprised if experts are slower with Direct Manipulation systems than with command language systems."

Experts may well be faster using commands and function keys, but in a rapidly expanding commercial marketplace, novices outnumbered experts. Once they are familiar with an interface, people often do not switch for a promise of better performance—if they did, the Dvorak keyboard would be more popular. Experienced users are continually adopting new features and applications. All in all, it was rational to focus on initial experience.

More powerful networking and processing led to collaboration support, hypertext and hypermedia, and then mobile and ubiquitous computing. As each moved from research to discretionary use, CHI increased coverage and sponsored relevant conference series: Computer Supported Cooperative Work (CSCW, first in 1986), Hypertext (1987), and Ubicomp (1999). CSCW represented a particularly significant shift, adding social theory and methods, including ethnography, to the previously cognitive orientation.

Conversely, technologies that became routine or confined to a niche faded from view at CHI. Papers on command languages, editors, UIMSs, and programmer support disappeared.

Color, animation, and sound added engagement and seduction to interface design in the competitive software industry. Interface design as a wholly scientific endeavor became untenable. CHI has sponsored the Designing Interactive Systems (DIS) conference series since 1995 and cosponsored Designing User Experience (DUX) since 2003. DIS attracts both systems and visual designers; DUX focuses on the latter.

Web site design introduced a new challenge. A site owner wishes to keep users at a given site; users may prefer to escape quickly. For a CHI professional whose self-perception is "user advocate," designing for Web site owners introduces a stakeholder conflict. This dilemma did not arise with individual productivity tools. Marketing, not an aspect of cognitive or computer science and often at loggerheads with R&D in organizations, has a foot in the door.[43]

Evolution of methods and theory

Psychologists who shaped CHI, like those who formed HF&E 30 years earlier, were trained to test hypotheses about behavior in laboratory experiments. Experimental subjects agree to follow instructions for an extrinsic reward. This is a good model for nondiscretionary use, but not for discretionary use. CHI researchers relabeled them "participants," which sounds volitional, but lab findings require confirmation in real-world settings more often than is true for ergonomics studies.

Traditional ergonomic goals apply—fewer errors, faster performance, quicker learning, greater memorability, and being enjoyable—but the emphasis differs. For power plant operation, error reduction is key, performance enhancement is good. Other goals are less critical. In contrast, consumers often respond to visceral appeal at the expense of usability and utility. CHI slowly abandoned its roots in science and engineering, although the adoption of the term *funology* suggests a wistful reluctance to do so. Will funology be researched only in the lab?[44]

Unlike HF&E, CHI embraced quick-and-dirty lab studies and time-consuming qualitative approaches. The former can guide real-world studies or help select among alternatives when the optimal solution is not needed. The latter can provide deeper understanding of user behaviors; challenges communicating such understandings led to methodological innovations such as contextual design and personas.[45]

Some early CHI researchers worked on theoretical foundations for design based on command naming and line editing as reference tasks.[46] GUIs curtailed interest in these topics. As the design space expanded, hope of establishing an overarching theory contracted. Application of modern cognitive theory is today more often found in cognitive science, HF&E, and IS. A recent compilation of HCI theory and modeling approaches includes several with a cognitive orientation and a few social science or cognitive-social hybrids.[47] That only one chapter focuses on computer science reveals the atheoretical nature of CHI's shift toward computer science over the past two decades.

Table 1. Submission and acceptances rates (medians rounded to 10%).

Field	Journals: Annual Submissions	Journals: % Accepted	Conferences: % Accepted
Human Factors and Ergonomics	150	30	80
Information Systems	200	10	60
Computer–Human Interaction	50	30	20

Moore's law exempts software invention from the usual tangled dance of engineering and science. Faster, smaller, and cheaper hardware ensures a steady flow of new devices and features, and more complex and layered architectures. Mobile devices, remote sensors and actuators, higher resolution, color, animation, voice over IP, application program interfaces (APIs), user interface libraries, and communication protocols spawn new choices. Research opportunities arise from indirect effects of spreading use on privacy, security, work-life balance, and so on.

The evolution of CHI is reflected in the influential contributions of Donald Norman. A cognitive scientist who coined 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 *Psychology of Everyday Things* focused on pragmatic usability. Its 1990 reissue as *Design of Everyday Things* reflected the broad 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.[48]

Discussion: Cultures and bridges

Despite a significant common focus, there has been limited interaction among the three threads of human–computer interaction research. This has not been for lack of trying. This section outlines some obstacles to interaction and efforts to overcome them.

Three communities, two academic cultures

The first two HCI disciplines to emerge, HF&E and IS, arose before discretionary hands-on use was widespread. Researchers in each considered both organizational and technical issues. They shared journals; the Benbasat and Dexter paper published in *Management Science* cited five *Human Factors* articles.

HF&E and IS also share the traditional academic culture of the sciences: Conferences are venues for work in progress, journals are repositories for polished work. In contrast, for CHI and other US computer science disciplines, conference proceedings are the final destination for most work. Journals are secondary. Outside the US, computer science retains more of a journal focus, perhaps due to the absence of professional societies that archive proceedings.[49] This circumstance impedes communication across disciplines and continents. Researchers in journal cultures chafe at CHI's rejection rates; CHI researchers are dismayed by the relatively unpolished work at other conferences.

Table 1 presents figures obtained from editors of leading conferences and journals.[50] CHI conferences are selective. CHI journals receive fewer submissions despite higher acceptance rates. These patterns were confirmed in interviews. Many CHI researchers state that journals are not relevant. Only about 10 percent of work in CHI-sponsored conferences reaches journal publication. In contrast, a Hawaii International Conference on System Sciences 2004 track organizer estimated that 80 percent of research there progressed to a journal.[51]

A linguistic divide also set CHI apart. HF&E and IS used the term *operator;* in IS, *user* could be a manager who used printed computer output, not a hands-on *end user*. Within CHI, *operator* was demeaning, *user* was always hands-on, and *end user* seemed a superfluous affectation.

In HF&E and IS, *task analysis* referred to an organizational decomposition of work; in CHI it was a cognitive decomposition, such as breaking a text editing *move* operation into *select, cut, select, paste*. In IS, *implementation* meant deployment of a system in an organization; in CHI it was a synonym for development. *System*, *application,* and *evaluation* also had markedly different connotations or denotations. Significant misunderstandings and rejections resulted from failure to recognize these distinctions.[52]

Different perspectives and priorities were reflected in attitudes toward standards. Many HF&E researchers contributed to standards development and argued that standards contribute to efficiency and innovation. Widespread in CHI was the view that standards inhibit innovation.

A generational divide also existed. Many CHI researchers grew up in the 1960s and 1970s, and did not appreciate the HF&E orientation toward military and government systems, or the fondness of HF&E and IS for male generics (for example, "man–machine" interaction). This reduced enthusiasm for building bridges and exploring literatures.

Efforts to find common ground

The Human Factors Society was deeply involved with the first CHI conference, but as CHI leaders wrote of human factors' "second class" status and embraced computer science, human factors professionals abandoned CHI. In recent interviews, some recalled feeling that CHI researchers believed incorrectly that they had discovered the topic, ignored human factors contributions, employed usability study methods that were insufficiently rigorous, and seemed more interested in "describing their experiences." Some CHI papers were indeed descriptive, and the widely used "thinking-aloud" verbal protocols, introduced to interface design by Clayton Lewis based on the theories of Allen Newell and Herb Simon, were not widely accepted in experimental psychology.[53]

The Computer Supported Cooperative Work conference series tried to bridge IS and CHI and met a similar fate. IS participation on the program committee and program, initially one-third, steadily declined. By 2002 no one on the program committee had a primary IS affiliation. In the early 1990s, IS papers were routinely rejected. In interviews, IS researchers said that CSCW reviewers "were not interested in IS contributions" or expected unrealistic effort for conference publications that count little in a field that regards conference papers as work in progress.

IS participation in CSCW was disproportionately represented by Scandinavian cooperative or participatory design, which appealed to many in CHI. This situation might seem odd on the surface. Participatory design shared the traditional IS focus in internal development and operation, not product design. It was overtly political, whereas CHI was scrupulously apolitical. However, both focused on discretion: The key Scandinavian goal was to let workers control technology choices. In addition, most Scandinavian and CHI researchers were of the same generation, influenced by the culture of the 1960s and 1970s. This alliance faded as differences became more apparent, albeit more slowly than the management IS tie.

Today, AIS SIGHCI seeks a cognitive bridge between IS and CHI, but the cultural forces must be reckoned with. Although SIGHCI does not mention HFES, it has organized sessions and special issues for the human factors-oriented HCII conference and journals *Behaviour and Information Technology, International Journal of Human–Computer Studies*, and *International Journal of Human–Computer Interaction*. High-acceptance, work-in-progress conference sessions that yield human factors and IS journal special issues will draw few CHI researchers. Cultural constraints can overpower apparent shared interests.

Other activities and perspectives

Another thread of human–computer interaction research is coalescing as *information science*, with conferences, journals, and societies that address database use, information retrieval, and the digital evolution of library science. One component of information science research can be traced to office automation efforts that sprang up around minicomputers in the 1970s, between the mainframes that spawned information systems and the PCs of CHI. The Web-based shift to information repositories returned this thread to prominence.

More could be said about the telecommunications industry. It had the most external customers and internal employees, and influenced every facet of HCI research.[54] Software engineering and artificial intelligence are relevant disciplines passed over here. Finally, by emphasizing tendencies around choice and mandate, this account bypasses research on interactive graphics and other technical contributions.

Trajectories

Human–computer interaction has been a particularly dynamic field, in large part due to the steady increase in hardware capability. Understanding past and present trends may provide some help in anticipating directions the field could take.

Discretion—Now you see it, now you don't

We exercise choice more at home than at work; a lot when buying online, none when confronted by a telephone answering system; considerable when young and healthy, less when constrained by injury or aging. Alternatives disappear: Software that was discretionary yesterday is indispensable today, and the need to collaborate forces us to adopt common systems and conventions.

Consider a hypothetical team. In 1985, one member still used a typewriter, others chose different word processors. They exchanged printed documents. One emphasized phrases by underlining, another by *italicizing*, a third by **bolding**. In 1995, in order to share documents digitally, group members had to adopt the same word processor and conventions. Choice was curtailed; it had to be exercised collectively. Technology can restore discretion: If it suffices to share documents in PDF format, in 2005 the team can use different word processors again, and one can envision a capability that allows me to see in italics what you see as bold.

Shackel noted the progression under the heading "From Systems Design to Interface Usability and Back Again."[5] Early designers focused at the system level and 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. When a technology becomes mission-critical, as email did for many in the 1990s, discretion is gone.

The converse also occurs. Discretion increases when employees download free software and demand capabilities they have at home. Managers are less likely to mandate the use of a technology that they use and find burdensome. For example, speech recognition systems appealed to military officers who anticipated that subordinates would use them. When senior officers become users, the situation changed:

> 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.[55]

As familiar applications become essential, and as security concerns curtail openness, one might expect discretion to recede, but Moore's law, greater competition, and more efficient distribution guarantee that a steady flow of unproven technologies will find their way to us.

Looking ahead

Will three HCI fields endure? Perhaps not, perhaps HCI goals will be realized only when it ceases to be a field of research altogether. In 1988, Norman wrote of "the invisible computer of the future."[56] Like motors, he speculated, computers would be present everywhere and visible nowhere. We interact with clocks, refrigerators, and cars. Each has a motor, but there is no human–motor interaction specialization. A decade later, at the height of the Y2K crisis and the Internet bubble, computers were more visible than ever. We may always want a multipurpose display or two, but part of Norman's vision is materializing. With computers embedded everywhere, concern with our interaction with them is everywhere. Today, as interaction with digital technology is becoming part of everyone's research, the three HCI fields are losing participation.

Human factors and ergonomics. Imperatives to improve training, expert performance, and error handling have strong continued support from government and the private sector. David Meister, author of *The History of Human Factors and Ergonomics*, 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 are 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 …[57]

Where among the 22 HFES technical groups is HCI represented? Membership in the Computer Systems Technical Group has declined sharply, but technology use is stressed in Cognitive Engineering and Decision Making, Communication, Human Performance Modeling, Internet, System Development, and Virtual Environment technical groups. Nor can Aging, Medical Systems, or others avoid "invisible computers." HCI papers appear without an HCI label.[58]

Information systems. As IS thrived in the 1990s, other management school disciplines—finance, marketing, operations research, organizational behavior—become more technically savvy. When the bubble burst and enrollments declined, IS was left with a less well-defined niche.

IS research issues, including HCI, remain significant, but this cuts two ways. With IT operation standardization and outsourcing, Web portals and business-to-business ties get more attention. Along with novel HCI issues, they bring in economic and marketing considerations, making it easier for HCI functions to be absorbed by traditional management disciplines. Some IS departments and individuals are aligning with computer science or information science, rather than management.

Computer–human interaction. This nomadic group started in psychology, obtained a place at the edge of the table in computer science, and is increasingly drawn to information science. Lacking a well-defined academic niche, CHI's identity is tied to its conference, and CHI conference participation has dropped as specialized conferences thrive.

The focus on discretionary use is under pressure as technologies appear and spread at an ever-increasing pace. When an emerging technology was slower to attract a critical mass of users, researchers on the topic first contributed to existing conferences and journals. Today, groups focused on new technologies can split off quickly. For example, soon after the Web emerged, annual WWW conferences drew papers on HCI issues. High conference rejection rates and a new generational divide could accelerate this dispersion of effort as successful conferences are established for ubiquitous and pervasive computing, agents, design, and so on. HCI is invisibly present in each.

Conclusion

This review of human–computer interaction explores efforts that might benefit from closer coordination but have remained distinct—if anything, moving apart over time. CHI focuses on invention and design; some of its engineering and modeling components have migrated to HF&E. A commercial software company employee familiar with the human factors community said (in a Sept. 2004 email communication to me from Edie Adams), "After all these years I've concluded that we use the same methods, we study the same things, but we do it to get new ideas, and they do it to improve what already exists."

CHI and IS could learn from one another. CHI discovered the limitations of laboratory studies and surveys for understanding discretionary use. Many IS researchers now focused on discretionary use still favor these techniques. IS has a more developed awareness of economic, organizational, and marketing theory and practice than CHI. But strong cultural barriers separate the two.

Moore's law ensures that landscapes will shift for some time, providing new forms of interaction to explore, new practices to improve. A younger generation has grown up with game consoles and cell phones; communicating with IM and text messaging; developing skills at searching, browsing, tagging, and synthesizing; and acquiring multimedia authoring talent via digital cameras and blogs. However it comes to be defined and wherever it is studied, human–computer interaction is still in its early days.

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