A Brief History of Human Computer Interaction Technology

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Human-Computer Interaction Technology

Brad A. Myers

Research in human–computer interaction (HCI) has been spectacularly successful and has fundamentally changed computing. One example is the ubiquitous graphical interface used by Microsoft Windows 95, which is based on the Macintosh, which is based on work at Xerox PARC, which in turn is based on early research at the Stanford Research Laboratory (now SRI) and at Massachusetts Institute of Technology.

Another example is that virtually all software written today employs user interface toolkits and interface builders—concepts that were developed first at universities. Even the remarkable growth of the World Wide Web is a direct result of HCI research: applying hypertext technology to browsers allows one to traverse a link across the world with a click of the mouse. More than anything else, improvements to interfaces have triggered this explosive growth. Furthermore, the research that will lead to the user interfaces for the computers of tomorrow is being carried out today at universities and a few corporate research labs.

This paper attempts to briefly summarize many of the important research developments in HCI technology, emphasizing the role of university research, which may not be widely recognized. By "research," I mean exploratory work at universities and government and corporate research labs (such as Xerox PARC) that is not directly related to products. By "HCI technology," I am referring to the computer side of HCI. A companion article on the history of the "human side," discussing contributions from psychology, design, human factors, and ergonomics would also be appropriate.

Figure 1 shows the time span for some of the technologies discussed in this article. including when they were introduced. Of course, a deeper analysis would reveal significant interaction among the university, corporate research, and commercial activity lines. It is important to appreciate that years of research are involved in creating and making these technologies ready for widespread use. The same will be true for the HCI technologies currently being developed that will provide the interfaces of tomorrow.

Clearly it is impossible to list every system and source in a paper of this scope, but I have tried to represent the earliest and most influential systems. Further information can be found in other surveys of HCI topics (see, for example, [1, 11, 36, 41]). Another useful resource is the video *All The Widgets,* which shows the historical progression of a number of user interface ideas [27].

The technologies discussed in this paper include fundamental interaction styles such as direct manipulation, the mouse pointing device, and windows; several important kinds of application areas, such as drawing, text editing, and spreadsheets; the technologies that will likely have the biggest impact on interfaces of the future, such as gesture recognition, multimedia, and three-dimensionality; and the technologies used to *create* interfaces using the other technologies, such as user interface management systems, toolkits, and interface builders.

Basic Interactions
Direct Manipulation of Graphical Objects

The now ubiquitous direct manipulation interface, where visible objects on the screen are directly manipulated with a pointing device, was first demonstrated by Ivan Sutherland in Sketchpad [47], the thesis of his doctoral dissertation in 1963. Sketchpad supported the manipulation of objects using a light pen, including grabbing objects, moving them, changing size, and using constraints. It contained the seeds of myriad important interface ideas. The system was built at Lincoln Labs with support from the U.S. Air Force and the National Science Foundation (NSF).
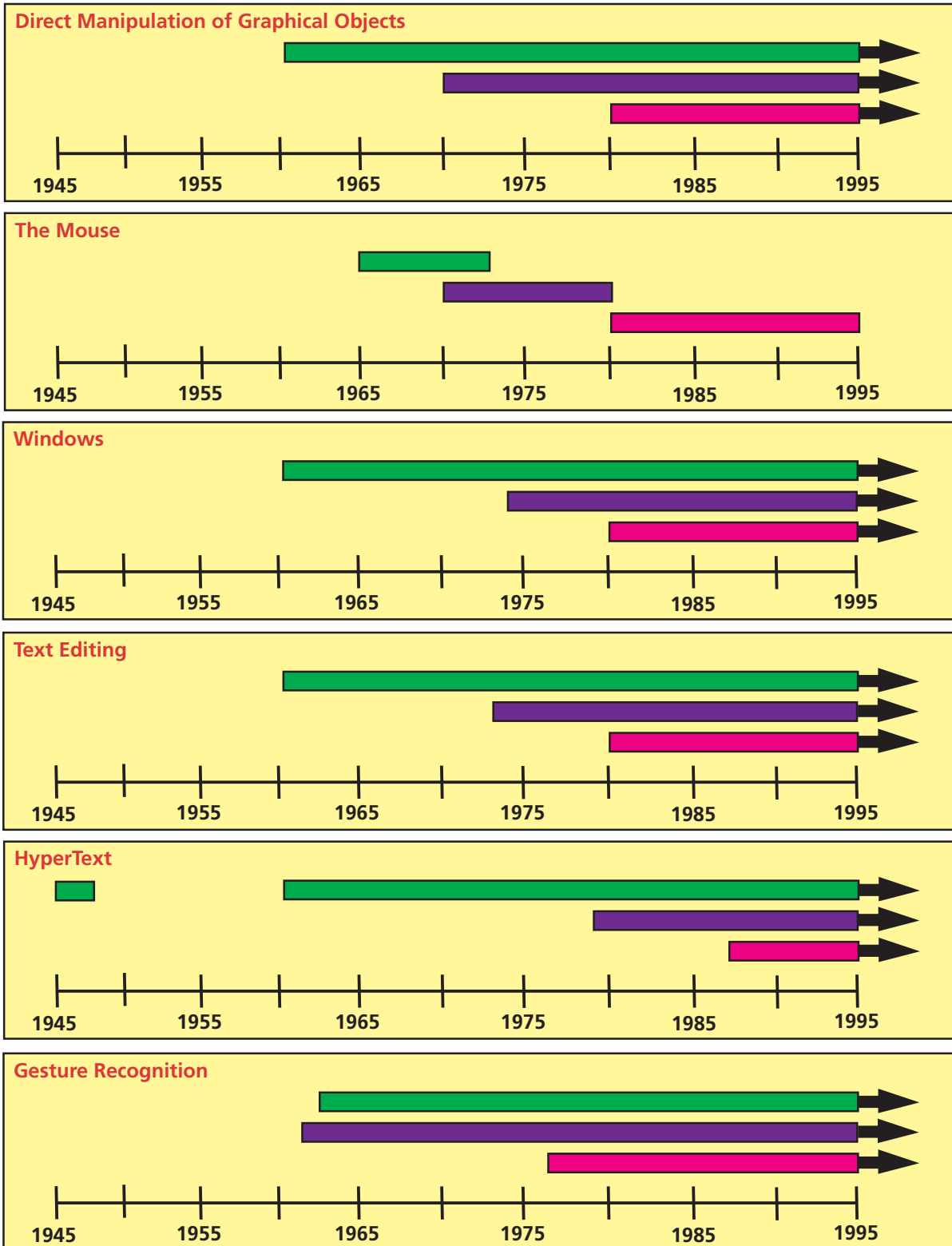
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KEY:
- University Research
- Corporate Research
- Commercial Products

Figure 1. Approximate time lines showing where and when work was performed on some major technologies discussed in this article.

Direct Manipulation of Graphical Objects

1945 · 1955 · 1965 · 1975 · 1985 · 1995

The Mouse

1945 · 1955 · 1965 · 1975 · 1985 · 1995

Windows

1945 · 1955 · 1965 · 1975 · 1985 · 1995

Text Editing

1945 · 1955 · 1965 · 1975 · 1985 · 1995

HyperText

1945 · 1955 · 1965 · 1975 · 1985 · 1995

Gesture Recognition

1945 · 1955 · 1965 · 1975 · 1985 · 1995

William Newman's Reaction Handler [33], created at Imperial College, London during 1966 and 1967, provided direct manipulation of graphics and introduced Light Handles [32], a form of graphical potentiometer that was probably the first "widget." Another early system was AMBIT/G (implemented at the Massachusetts Institute of Technology's (MIT) Lincoln Labs in 1968 and funded by the Advanced Research Projects Agency (ARPA). It employed, among other inter- face techniques, iconic repre- sentations, gesture recog- nition, dynamic menus with items selected using a point- ing device, selection of icons by pointing, and moded and mode-free styles of interaction.

David Canfield Smith coined the term "icons" in his 1975 doctoral thesis on Pyg- malion [44] (funded by ARPA and National Institute of Mental Health – NIMH). Smith later popu- larized icons as one of the chief designers of the Xerox Star [45]. Many of the interac- tion techniques popular in direct manipula- tion interfaces, such as how objects and text are selected, opened, and manipulated, were researched at Xerox PARC in the 1970s. In particular, the idea of "WYSIWYG" (what you see is what you get) originated there with systems such as the Bravo text editor and the Draw drawing program [11]

The concept of direct manipulation inter- faces for everyone was envisioned by Alan Kay of Xerox PARC in a 1977 article about the Dynabook [18]. The first commercial systems to use direct manipulation extensively were the Xerox Star (1981) [45], the Apple Lisa (1982) [54], and the Macintosh (1984) [55]. Ben Shneiderman at the University of Maryland coined the term "direct manipulation" in 1982, identified the components, and gave psycholog- ical motivations for direct manipulation [43].

Mouse

The mouse was developed at Stanford Research Laboratory in 1965 as part of the NLS project (funding from ARPA, NASA, and Rome ADC) [10]. It was intended to be a cheap replacement for light pens, which had been used at least since 1954 [11, p. 68]. Many of the current uses of the mouse were demonstrated by Doug Engelbart as part of NLS in a movie created in 1968 [9]. The mouse was then made famous as a practical input device by Xerox PARC in the 1970s. It first appeared commercially as part of the Xerox Star (1981), the Three Rivers Computer Company's PERQ (1981) [25], the Apple Lisa (1982), and the Apple Macintosh (1984).
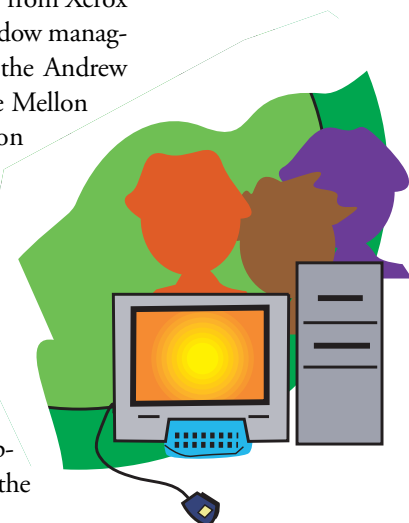
Windows

Multiple tiled windows were demonstrated in Engelbart's NLS in 1968 [9]. Early research at Stan- ford on systems like COPI- LOT (1974) [49] and at MIT with the EMACS text editor (1974) [46] also demonstrated tiled windows. Alan Kay proposed the idea of overlapping windows in his 1969 doctoral thesis [17], and overlapping windows first appeared in 1974 in his Smalltalk system [12] at Xerox PARC, and soon afterward in the InterLisp system [50].

Some of the first commercial uses of win- dows were on Lisp Machines Inc. (LMI) and Symbolics Lisp Machines (1979), which grew out of MIT Artificial Intelligence (AI) Lab pro- jects. The Cedar Window Manager from Xerox PARC was the first major tiled window manag- er (1981) [48], followed soon by the Andrew window manager [35] by Carnegie Mellon University's (CMU) Information Technology Center (1983, funded by IBM). The main commercial systems popularizing windows were the Xerox Star (1981), the Apple Lisa (1982), and most important, the Apple Macin- tosh (1984). The early versions of the Star and Microsoft Windows were tiled, but eventually they sup- ported overlapping windows like the

> "THE SKETCHPAD SYSTEM MAKES IT POSSIBLE FOR A MAN AND A COM- PUTER TO CON- VERSE RAPIDLY THROUGH THE MEDIUM OF LINE DRAWINGS."
>
> — IVAN SUTHERLAND [47, P. 329]

Lisa and Macintosh. The X Window System, a current international standard, was developed at MIT in 1984 [42]. For a survey of window managers, see [26].

Applications

Drawing Programs

Much of the current technology for drawing programs was demonstrated in Sutherland's 1963 Sketchpad system [47]. The use of a mouse to manipulate graphics was demonstrated in NLS (1965). In 1968 Ken Pulfer and Grant Bechthold at the National Research Council of Canada built a mouse out of wood patterned after Engelbart's mouse and used it with a key-frame animation system to draw all the frames of a movie. A subsequent movie in 1971, *Hunger,* won a number of awards and was drawn using a tablet instead of the mouse (funding by the National Film Board of Canada) [3]. William Newman's Markup (1975) was the first drawing program for Xerox PARC's Alto, followed shortly by Patrick Baudelaire's Draw, which added handling of lines and curves [11, p. 326]. The first computer painting program was probably Dick Shoup's Superpaint at PARC (1974–1975). The first widely used drawing programs were MacPaint and MacDraw on the Macintosh (1984).
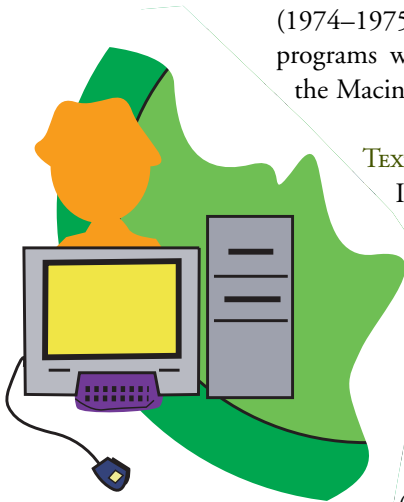
Text Editing

In 1962, at the Stanford Research Laboratory, Engelbart proposed, and later implemented, a word processor with automatic word wrap, search and replace, user-definable macros, scrolling text, and commands to move, copy, and delete characters, words, or blocks of text. Stanford's TVEdit (1965) was one of the first CRT-

based display editors that was widely used [51]. The Hypertext Editing System [53, p. 108] from Brown University had screen editing and formatting of arbitrary-sized strings with a light pen in 1967 (funding from IBM). NLS demonstrated mouse-based editing in 1968 (Figure 4). TECO from MIT was an early screen editor (1967), and EMACS [46] was developed from it in 1974. Xerox PARC's Bravo [11, p. 284] was the first WYSIWYG editor-formatter (1974). It was designed by Butler Lampson and Charles Simonyi, who had started working on these concepts about 1970 while at Berkeley. The first commercial WYSIWYG editors were the Star, LisaWrite, and, later, MacWrite. For surveys of text editors, see [24] and [53].

Spreadsheets

The initial spreadsheet was Visi-Calc which was developed by Frankston and Bricklin (1977–1978) for the Apple II while they were students at MIT and the Harvard Business School, respectively. The solver was based on a dependency-directed backtracking algorithm by Sussman and Stallman at the MIT AI Lab.

HyperText

The idea for hypertext (by which documents are linked to related documents) is credited to Vannevar Bush's famous MEMEX idea from 1945 [4]. Ted Nelson coined the term "hypertext" in 1965 [31]. Engelbart's NLS system [9] at the Stanford Research Laboratories in 1965 made extensive use of linking (funding from ARPA, NASA, and Rome ADC). The "NLS Journal" [11, p. 212] was one of the first on-line journals and included full linking of articles (1970). The Hypertext Editing System, jointly designed by Andy van Dam, Ted Nelson, and two students at Brown University (funding from IBM) was distributed extensively [52].

> "THE DIFFICULTY OF MANKIND'S PROBLEMS WAS INCREASING AT A GREATER RATE THAN OUR ABILITY TO COPE. (WE ARE IN TROUBLE.) [SO] I … COMMITTED MY CAREER TO 'AUGMENTING THE HUMAN INTELLECT.'"
>
> — DOUG ENGELBART, ON THE NLS SYSTEM [8, P. 189]

The University of Vermont's PROMIS (1976) was the first hypertext system released to the user community. It was used to link patient and patient care information at the University of Vermont's medical center. The ZOG project (1977) from CMU was another early hypertext system and was funded by Office of Naval Research (ONR) and ARPA [39]. Ben Shneiderman's Hyperties was the first system in which highlighted items in the text could be clicked on to go to other pages (1983, University of Maryland) [19]. HyperCard from Apple (1988) significantly helped to bring the idea to a wide audience.

Tim Berners-Lee used the hypertext idea to create the World Wide Web in 1990 at the government-funded European Particle Physics Laboratory (CERN). Mosaic, the first popular hypertext browser for the World-Wide Web, was developed at the University of Illinois' National Center for Supercomputer Applications (NCSA). For a more complete history of HyperText, see [34].

Computer-Aided Design

The same 1963 International Federation of Information Processing Societies (IFIPS) conference at which Sketchpad was presented also contained a number of computer-aided design (CAD) systems, including Doug Ross's Computer-Aided Design Project at MIT in the Electronic Systems Lab [40] and Coons's work at MIT with Sketch-Pad [7]. Timothy Johnson's pioneering work on the interactive 3D CAD system Sketchpad 3 [15] was his doctoral thesis in 1963 (funded by the U.S. Air Force). The first system in industry using CAD and computer-

aided manufacturing (CAM) was probably General Motor's DAC-1 (about 1963).

Video Games

The first graphical video game was probably SpaceWar by Slug Russel of MIT in 1962 for the PDP-1 [21, p. 49], including the first computer joysticks. The early computer Adventure game was created by Will Crowther at Bolt, Beranek & Newman (BBN), and Don Woods developed it into a more sophisticated Adventure game at Stanford in 1966 [21, p. 132]. Conway's game of LIFE was developed on computers at MIT and Stanford in 1970. The first popular commercial game was Pong (about 1976).

Up-and-Coming Areas

Gesture Recognition

The first pen-based input device, the Rand tablet, was funded by ARPA. Sketchpad used light-pen gestures (1963). Teitelman in 1964 developed the first trainable gesture recognizer. A very early demonstration of gesture recognition was Tom Ellis's GRAIL system on the Rand tablet (1964, funded by ARPA). It was quite common in light-pen–based systems to include some gesture recognition, for example in the AMBIT/G system (1968, funded by ARPA). A gesture-based text editor using proofreading symbols was developed at CMU by Michael Coleman in 1969. Bill Buxton at the University of Toronto has been studying gesture-based interactions since 1980. Gesture recognition has been used in commercial CAD systems since the 1970s and came to universal notice with the Apple Newton in 1992.
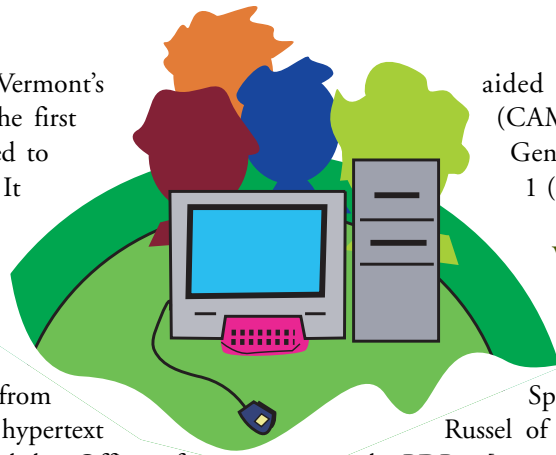
> "MULTIPLE WINDOWS ALLOW A DOCUMENT (COMPOSED OF TEXT, PICTURES, MUSICAL NOTATION) TO BE CREATED AND VIEWED SIMULTANEOUSLY AT SEVERAL LEVELS OF REFINEMENT."
>
> — ALAN KAY, ON SMALLTALK-72 [18, P. 34].

Multimedia

The FRESS project at Brown University used multiple windows and integrated text and graphics (1968, funding from industry). The Interactive Graphical Documents project at Brown was the first hypermedia (as opposed to hypertext) system and used raster graphics and text but not video (1979–1983, funded by ONR and NSF). The Diamond project at BBN (starting in 1982, funded by ARPA) explored combining multimedia information (text, spreadsheets, graphics, speech). The Movie Manual at the Architecture Machine Group (MIT) was one of the first to demonstrate mixed video and computer graphics in 1983 (funded by ARPA).

Three-Dimensionality

The first 3D system was probably Timothy Johnson's 3D CAD system mentioned earlier (1963, funded by the U.S. Air Force) [15]. The Lincoln Wand by Larry Roberts was an ultrasonic 3D location sensing system developed at Lincoln Labs (1966, funded by ARPA). That system also had the first interactive 3D hidden line elimination. An early use was for molecular modeling [20]. The late 1960s and early 1970s saw the flowering of 3D raster graphics research at the University of Utah with Dave Evans, Ivan Sutherland, G.W. Romney, Henri Gouraud, Bui-Tuong Phong, and G.S. Watkins, much of it government funded. Also, the military-industrial flight simulation work of the 1960s and 1970s led the way to making 3D interfaces operate in real time on commercial systems from General Electric, Evans & Sutherland, Singer/Link (funded

> THE 'MOUSE' WAS DEVELOPED BY SRI. IT IS CONSTRUCTED FROM TWO POTENTIOMETERS, MOUNTED ORTHOGONALLY, EACH OF WHICH HAS A WHEEL ATTACHED TO ITS SHAFT. THE MOUNTING FRAME … IS ENCLOSED IN A 2 INCH X 2 INCH X 4 INCH WOODEN CASE."
>
> — W.K. ENGLISH, D.C. ENGELBART, AND M.L. BERMAN, ON THE NLS SYSTEM [10, P. 7]

by NASA, U.S. Navy, and others). Another important center of current research on 3-D interfaces is Fred Brooks's lab at University of North Carolina at Chapel Hill (e.g., [2]).

## Virtual Reality and "Augmented Reality"

The original work on virtual reality (VR) was performed by Ivan Sutherland when he was at Harvard (1965–1968, funding by Air Force, Central Intelligence Agency, and Bell Laboratories). Very important early work was done by Tom Furness when he was at Wright-Patterson AFB. Myron Krueger's early work at the University of Connecticut on interfaces that incorporate and interpret a video of the user was influential. Fred Brooks's and Henry Fuch's groups at UNC did a lot of early research, including the study of force feedback (1971, funding from U.S. Atomic Energy Commission and NSF). Much of the early research on head-mounted displays and on the DataGlove was supported by NASA.

Computer-Supported Cooperative Work

Doug Engelbart's 1968 demonstration of NLS [9] included the remote participation of multiple people at various sites (funding from ARPA, NASA, and Rome ADC). Licklider and Taylor predicted online interactive communities in a 1968 article [22] and speculated about the problem of access being limited to the privileged. Electronic mail, still the most widespread multiuser software, was enabled by the ARPAnet, which became operational in 1969, and by the Ethernet from Xerox PARC in 1973. An early computer conferencing system was Turoff's EIES system at the New Jersey Institute of Technology (1975).
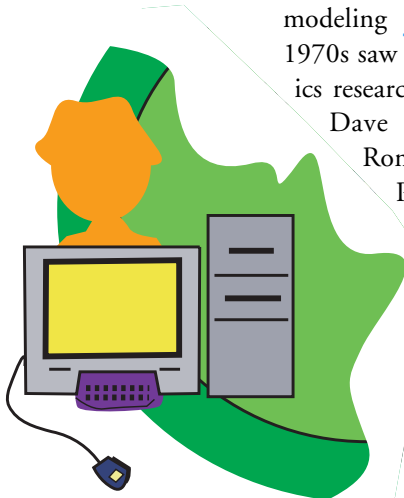
Natural Language and Speech

The fundamental research for speech and natural language understanding and generation has been performed at CMU, MIT, SRI, BBN, IBM, AT&T Bell Labs and BellCore, much of it government funded. See, for example, [37] for a survey of the early work.

Software Tools and Architectures

The area of user interface (UI) software tools is quite active now, and many companies are selling tools. Most of today's applications are implemented using various forms of software tools. For a more complete survey and discussion of UI tools, see [28].

User Interface Management Systems and Toolkits

User interface management systems (UIMS) and toolkits are software libraries and tools that help to create user interfaces. The first UIMS was William Newman's Reaction Handler [33] created at Imperial College, London (1966–1967 with SRC funding). Most of the early work was done at universities (University of Toronto with Canadian government funding; George Washington University with NASA, NSF, Department of Energy, and National Bureau of Standards (NBS) funding; Brigham Young University with industrial funding; and so on). The term "UIMS" was coined by David Kasik at Boeing (1982) [16]. Early window managers such as Smalltalk (1974) and InterLisp, both from Xerox PARC, came with a few widgets, such as popup menus and scrollbars. The Xerox Star (1981) was the first commercial system to have a large collection of widgets. The Apple Macintosh (1984) was the first to actively promote its toolkit for use by other developers to enforce a consistent interface. An early C++ toolkit was InterViews [23], developed at Stanford (1988, industrial funding). Much of the modern research is being performed at universities, for example, the Garnet (1988) [29] and Amulet (1994) [30] projects at CMU (funded by DARPA) and SubArctic at Georgia Tech (1996, funded by Intel and NSF) [14].

Interface Builders

Interface builders are interactive tools that allow interfaces composed of widgets such as buttons, menus, and scrollbars to be placed using a mouse. The Steamer project at BBN (1979–1985; funded by ONR) demonstrated many of the ideas later incorporated into interface builders and was probably the first object-oriented graphics system. Trillium [13] was developed at Xerox PARC in 1981.

Another early interface builder was the MenuLay system [5] developed by Bill Buxton at the University of Toronto (1983, funded by the Canadian Government). The Macintosh (1984) included a Resource Editor that allowed widgets to be placed and edited. Jean-Marie Hullot created SOS Interface in Lisp for the Macintosh while working at The French National Institute for Research in Computer Science and Control (INRIA) (1984, funded by the French government) which was the first modern interface builder. Hullot built this into a commercial product in 1986 and then went to work for NeXT and created the NeXT Interface Builder (1988), which popularized this type of tool. Now there are literally hundreds of commercial interface builders.

Component Architectures

The idea of creating interfaces by connecting separately written components was first demonstrated in the Andrew project [35] by Carnegie Mellon University's Information Technology Center (1983, funded by IBM). It is now being widely popularized by Microsoft's object linking and embedding (OLE), Apple and IBM's OpenDoc, and the Java Beans architectures.

Discussion

It is clear that all of the most important innovations in HCI have benefited from research at both corporate research labs and universities. One motivation for this article is to overcome the impressions some people may have that much of the important work in human–computer interaction occurred in industry and that if university research in
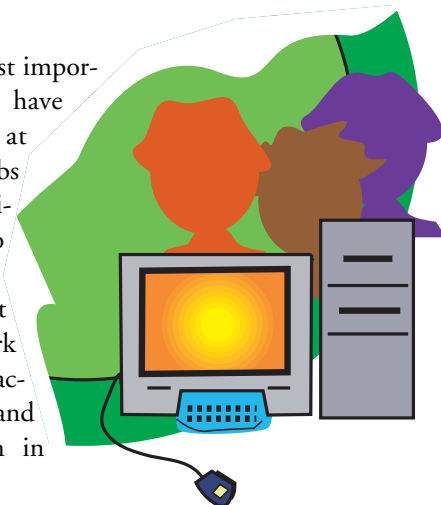
HCI is not supported, then industry will just carry on anyway. This is simply not true. I hope that this paper has shown that many of the most famous HCI successes developed by companies are deeply rooted in university research. In fact, virtually all of today's major interface styles and applications have been significantly influenced by research at universities and labs, often with government funding. To illustrate this point, this article has listed the funding sources of some of the major advances. Without this research, many of the advances in the field of HCI would probably not have taken place, and as a consequence, the user interfaces of commercial products would be far more difficult to use and learn than they are today. As described by Stu Card [6, p. 162]:

Government funding of advanced human-computer interaction technologies built the intellectual capital and trained the research teams for pioneer systems that, over a period of 25 years, revolutionized how people interact with computers. Industrial research laboratories at the corporate level in Xerox, IBM, AT&T, and others played a strong role in developing this technology and bringing it into a form suitable for the commercial arena.

Another important argument in favor of HCI research at universities is that computer science students need to know about user interface issues. User interfaces are likely to be one of the main value-added competitive advantages of the future as both hardware and basic software become commodities. If students do not know about user interfaces, they will not serve

industry needs. It seems that only through computer science does HCI research disseminate to products. Furthermore, without appropriate levels of funding of academic HCI research, there will be fewer doctoral graduates in HCI to perform research in corporate labs, and fewer top-notch graduates in this area will be interested in being professors, so the needed user interface courses will not be offered.

The conventional style of graphical user interfaces that use windows, icons, menus, and a mouse are in a phase of standardization, where almost everyone is using the same, standard technology and making small, incremental changes. As computers perform faster, more of the processing power is being devoted to the user interface. The interfaces of the future will use gesture recognition, speech recognition, "intelligent agents," adaptive interfaces, video, and many other technologies now being investigated by research groups at universities and corporate labs [38]. Therefore, it is imperative that university, corporate, and government-supported research continue and be well-supported, so that we can develop the science and technology needed for the user interfaces of the future.

"IN EMBEDDED MENUS, HIGHLIGHTED OR UNDERLINED WORDS OR PHASES WITHIN THE TEXT BECOME THE MENU ITEMS, AND ARE SELECTABLE USING THE COMMONLY USED TOUCH SCREEN, CURSOR AND MOUSE METHODS."
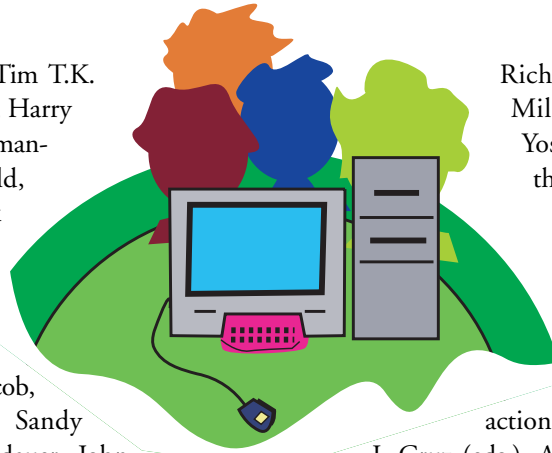
— L. KOVED AND B. SHNEIDERMAN ON THE HYPERTIES SYSTEM [19, P. 312].

Acknowledgments
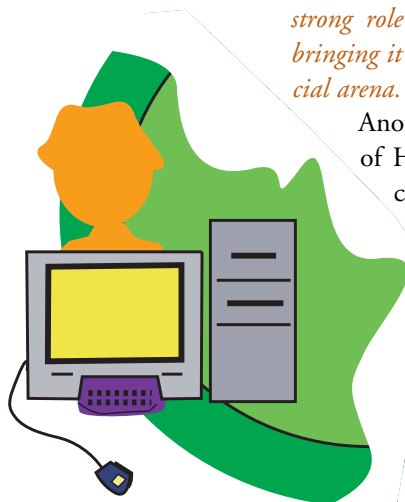
Diaper, Dick Duda, Tim T.K. Dudley, Steven Feiner, Harry Forsdick, Bjorn Freeman-Benson, John Gould, Wayne Gray, Mark Green, Fred Hansen, Bill Hefley, D. Austin Henderson, Jim Hollan, Jean-Marie Hullot, Rob Jacob, Bonnie John, Sandy Kobayashi, T.K. Landauer, John Leggett, Roger Lighty, Marilyn Mantei, Jim Miller, William Newman, Jakob Nielsen, Don Norman, Dan Olsen, Ramesh Patil, Gary Perlman, Dick Pew, Ken Pier, Jim Rhyne, Ben Shneiderman, John Sibert, David C. Smith, Elliot Soloway, Richard Stallman, Ivan Sutherland, Dan Swinehart, John Thomas, Alex Waibel, Marceli Wein, Mark Weiser, Alan Wexelblat, and Terry Winograd. Editorial comments were also provided by the foregoing as well as by Jim Hollan, Ellen Borison, Rich McDaniel, Rob Miller, Bernita Myers, Yoshihiro Tsujino, and the reviewers.

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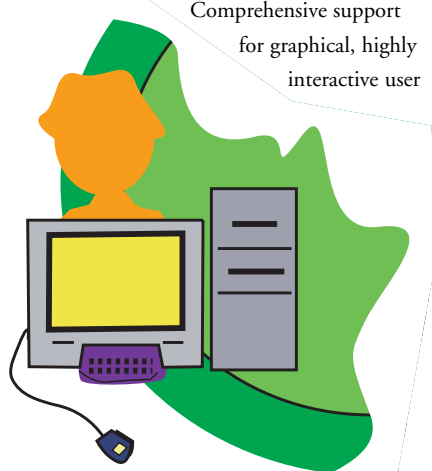
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