A Brief History of Human Computer Interaction Technology

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Abstract

This article summarizes the historical development of major advances in human-computer interaction technology, emphasizing the pivotal role of university research in the advancement of the field.

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1. Introduction

Research in Human-Computer Interaction (HCI) has been spectacularly successful, and has fundamentally changed computing. Just 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 the Massachusetts Institute of Technology. Another example is that virtually all software written today employs user interface toolkits and interface builders, concepts which were developed first at universities. Even the spectacular 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. Interface improvements more than anything else has triggered this explosive growth. Furthermore, the research that will lead to the user interfaces for the computers of tomorrow is happening at universities and a few corporate research labs.

This paper tries to briefly summarize many of the important research developments in Human-Computer Interaction (HCI) technology. 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 the contributions from psychology, design, human factors and ergonomics would also be appropriate.

A motivation for this article is to overcome the mistaken impression that much of the important work in Human-Computer Interaction occurred in industry, and if university research in Human-Computer Interaction is not supported, then industry will just carry on anyway. This is simply not true. This paper tries to show 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 had significant influence from research at universities and labs, often with government funding. To illustrate this, this paper lists 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:

> "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." [6, p. 162]).

Figure 1 shows time lines for some of the technologies discussed in this article. Of course, a deeper analysis would reveal much interaction between the university, corporate research and commercial activity streams. 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 that will provide the interfaces of tomorrow.

It is clearly 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. Although there are a number of other surveys of HCI topics (see, for example [1] [10] [33] [38]), none cover as many aspects as this one, or try to be as comprehensive in finding the original influences. Another useful resource is the video "All The Widgets," which shows the historical progression of a number of user interface ideas [25].

The technologies covered in this paper include fundamental interaction styles like 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 3D; and the technologies used to *create* interfaces using the other technologies, such as user interface management systems, toolkits, and interface builders.

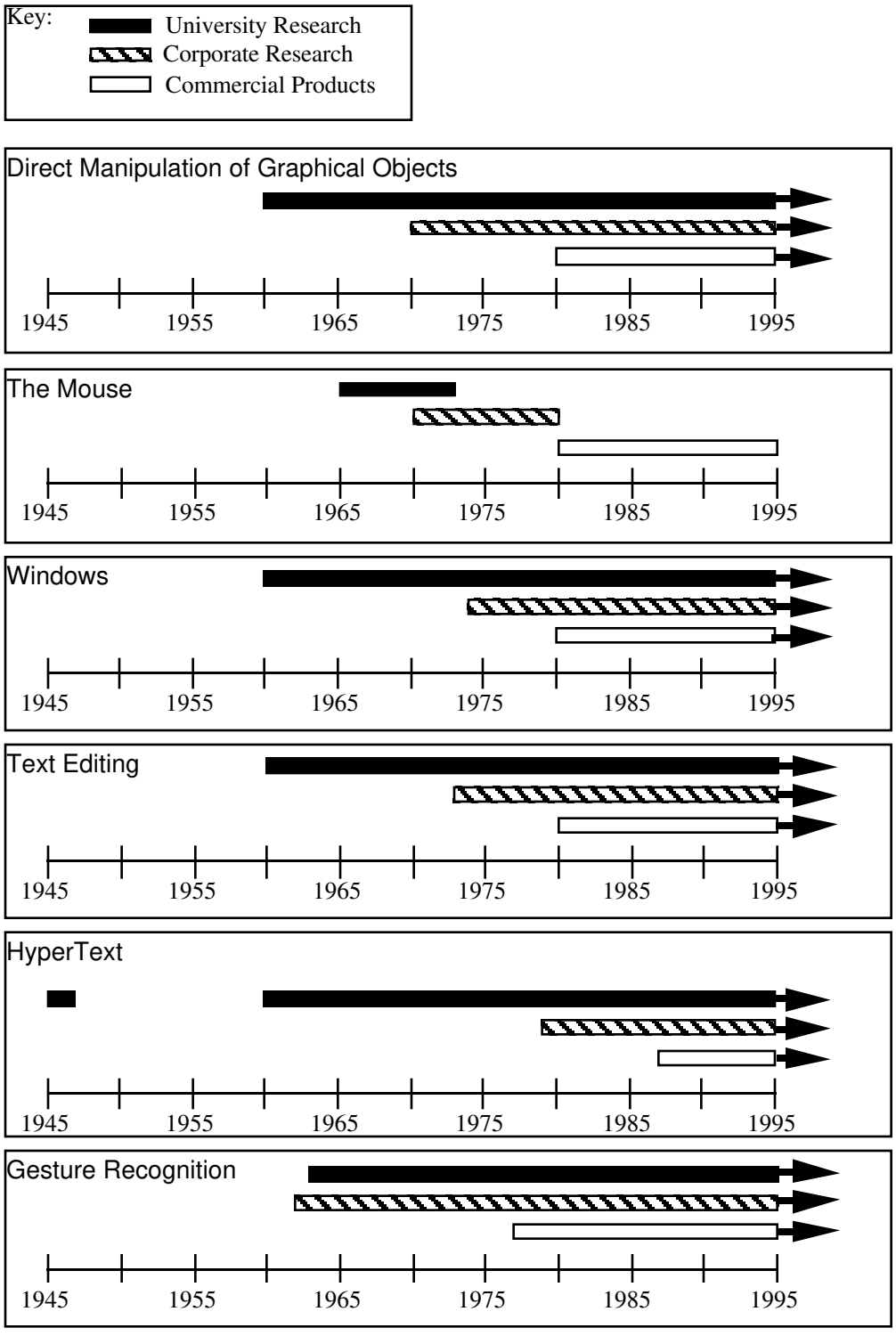

Figure 1: Approximate time lines showing where work was performed on some major technologies discussed in this article.

2. 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 [44], which was his 1963 MIT PhD thesis. 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 Air Force and NSF. William Newman's Reaction Handler [30], created at Imperial College, London (1966-67) provided direct manipulation of graphics, and introduced "Light Handles," a form of graphical potentiometer, that was probably the first "widget." Another early system was AMBIT/G (implemented at MIT's Lincoln Labs, 1968, ARPA funded). It employed, among other interface techniques, iconic representations, gesture recognition, dynamic menus with items selected using a pointing device, selection of icons by pointing, and moded and mode-free styles of interaction. David Canfield Smith coined the term "icons" in his 1975 Stanford PhD thesis on Pygmalion [41] (funded by ARPA and NIMH) and Smith later popularized icons as one of the chief designers of the Xerox Star [42]. Many of the interaction techniques popular in direct manipulation interfaces, such as how objects and text are selected, opened, and manipulated, were researched at Xerox PARC in the 1970's. 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 [10] The concept of direct manipulation interfaces for everyone was envisioned by Alan Kay of Xerox PARC in a 1977 article about the "Dynabook" [16]. The first commercial systems to make extensive use of Direct Manipulation were the Xerox Star (1981) [42], the Apple Lisa (1982) [51] and Macintosh (1984) [52]. Ben Shneiderman at the University of Maryland coined the term "Direct Manipulation" in 1982 and identified the components and gave psychological foundations [40].

- **The Mouse**: The mouse was developed at Stanford Research Laboratory (now SRI) in 1965 as part of the NLS project (funding from ARPA, NASA, and Rome ADC) [9] to be a cheap replacement for light-pens, which had been used at least since 1954 [10, 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 [8]. The mouse was then made famous as a practical input device by Xerox PARC in the 1970's. It first appeared commercially as part of the Xerox Star (1981), the Three Rivers Computer Company's PERQ (1981) [23], the Apple Lisa (1982), and Apple Macintosh (1984).

• **Windows**: Multiple tiled windows were demonstrated in Engelbart's NLS in 1968 [8]. Early research at Stanford on systems like COPILOT (1974) [46] and at MIT with the EMACS text editor (1974) [43] also demonstrated tiled windows. Alan Kay proposed the idea of overlapping windows in his 1969 University of Utah PhD thesis [15] and they first appeared in 1974 in his Smalltalk system [11] at Xerox PARC, and soon after in the InterLisp system [47]. Some of the first commercial uses of windows were on Lisp Machines Inc. (LMI) and Symbolics Lisp Machines (1979), which grew out of MIT AI Lab projects. The Cedar Window Manager from Xerox PARC was the first major tiled window manager (1981) [45], followed soon by the Andrew window manager [32] by Carnegie Mellon University's Information Technology Center (1983, funded by IBM). The main commercial systems popularizing windows were the Xerox Star (1981), the Apple Lisa (1982), and most importantly the Apple Macintosh (1984). The early versions of the Star and Microsoft Windows were tiled, but eventually they supported overlapping windows like the Lisa and Macintosh. The X Window System, a current international standard, was developed at MIT in 1984 [39]. For a survey of window managers, see [24].

3. Application Types

• **Drawing programs**: Much of the current technology was demonstrated in Sutherland's 1963 Sketchpad system. The use of a mouse for 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 and used it with a key-frame animation system to draw all the frames of a movie. A subsequent movie, "Hunger" in 1971 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 [10, p. 326]. The first computer painting program was probably Dick Shoup's "Superpaint" at PARC (1974-75).

• **Text Editing**: In 1962 at the Stanford Research Lab, 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 [48]. The Hypertext Editing System [50, p. 108] from Brown University had screen editing and formatting of arbitrary-sized strings with a lightpen in 1967 (funding from IBM). NLS demonstrated mouse-based editing in

1968. TECO from MIT was an early screen-editor (1967) and EMACS [43] developed from it in 1974. Xerox PARC's Bravo [10, 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 around 1970 while at Berkeley. The first commercial WYSIWYG editors were the Star, LisaWrite and then MacWrite. For a survey of text editors, see [22] [50, p. 108].

- **Spreadsheets**: The initial spreadsheet was VisiCalc which was developed by Frankston and Bricklin (1977-8) for the Apple II while they were students at MIT and the Harvard Business School. The solver was based on a dependency-directed backtracking algorithm by Sussman and Stallman at the MIT AI Lab.

- **HyperText**: The idea for hypertext (where 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 [29]. Engelbart's NLS system [8] at the Stanford Research Laboratories in 1965 made extensive use of linking (funding from ARPA, NASA, and Rome ADC). The "NLS Journal" [10, p. 212] was one of the first on-line journals, and it 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 [49]. 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 ONR and DARPA [36]. Ben Shneiderman's Hyperties was the first system where highlighted items in the text could be clicked on to go to other pages (1983, Univ. of Maryland) [17]. HyperCard from Apple (1988) significantly helped to bring the idea to a wide audience. There have been many other hypertext systems through the years. 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 Univ. of Illinois' National Center for Supercomputer Applications (NCSA). For a more complete history of HyperText, see [31].

- **Computer Aided Design (CAD)**: The same 1963 IFIPS conference at which Sketchpad was presented also contained a number of CAD systems, including Doug Ross's Computer-Aided Design Project at MIT in the Electronic Systems Lab [37] and Coons' work at MIT with SketchPad [7]. Timothy Johnson's pioneering work on the interactive 3D CAD system Sketchpad 3 [13] was his 1963 MIT MS thesis (funded by

the Air Force). The first CAD/CAM system in industry 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 [19, p. 49] including the first computer joysticks. The early computer Adventure game was created by Will Crowther at BBN, and Don Woods developed this into a more sophisticated Adventure game at Stanford in 1966 [19, p. 132]. Conway's game of LIFE was implemented on computers at MIT and Stanford in 1970. The first popular commercial game was Pong (about 1976).

4. 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' GRAIL system on the RAND tablet (1964, ARPA funded). It was quite common in light-pen-based systems to include some gesture recognition, for example in the AMBIT/G system (1968 — ARPA funded). A gesture-based text editor using proof-reading 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.

- **Multi-Media**: The FRESS project at Brown 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, DARPA funded) 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 (DARPA funded).

- **3-D:** The first 3-D system was probably Timothy Johnson's 3-D CAD system mentioned above (1963, funded by the Air Force). The "Lincoln Wand" by Larry Roberts was an ultrasonic 3D location sensing system, developed at Lincoln Labs (1966, ARPA funded). That system also had the first interactive 3-D hidden line elimination. An early use was for molecular modelling [18]. The late 60's and early 70's saw the flowering of 3D raster graphics research at the University of Utah with Dave Evans, Ivan Sutherland, Romney, Gouraud, Phong, and Watkins, much of it government funded.

Also, the military-industrial flight simulation work of the 60's - 70's led the way to making 3-D real-time with commercial systems from GE, Evans&Sutherland, Singer/Link (funded by NASA, Navy, etc.). Another important center of current research in 3-D is Fred Brooks' lab at UNC (e.g. [2]).

- **Virtual Reality and "Augmented Reality":** The original work on VR was performed by Ivan Sutherland when he was at Harvard (1965-1968, funding by Air Force, CIA, and Bell Labs). Very important early work was by Tom Furness when he was at Wright-Patterson AFB. Myron Krueger's early work at the University of Connecticut was influential. Fred Brooks' and Henry Fuch's groups at UNC did a lot of early research, including the study of force feedback (1971, funding from US 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 [8] included the remote participation of multiple people at various sites (funding from ARPA, NASA, and Rome ADC). Licklider and Taylor predicted on-line interactive communities in an 1968 article [20] and speculated about the problem of access being limited to the privileged. Electronic mail, still the most widespread multi-user 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, [34] for a survey of the early work.

5. Software Tools and Architectures

The area of user interface 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 [26].

- **UIMSs and Toolkits**: (There are software libraries and tools that support creating interfaces by writing code.) The first User Interface Management System (UIMS) was William Newman's Reaction Handler [30] created at Imperial College, London (1966-67 with SRC funding). Most of the early work was done at universities (Univ. of Toronto with Canadian government funding, George Washington Univ. with NASA, NSF, DOE, and NBS funding, Brigham Young University with industrial funding, etc.). The term

"UIMS" was coined by David Kasik at Boeing (1982) [14]. 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 [21], developed at Stanford (1988, industrial funding). Much of the modern research is being performed at universities, for example the Garnet (1988) [28] and Amulet (1994) [27] projects at CMU (ARPA funded), and subArctic at Georgia Tech (1996, funding by Intel and NSF).

- **Interface Builders:** (These 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 (1979-85; ONR funding) demonstrated many of the ideas later incorporated into interface builders and was probably the first object-oriented graphics system. Trillium [12] 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" which allowed widgets to be placed and edited. Jean-Marie Hullot created "SOS Interface" in Lisp for the Macintosh while working at 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 [32] by Carnegie Mellon University's Information Technology Center (1983, funded by IBM). It is now being widely popularized by Microsoft's OLE and Apple's OpenDoc architectures.

6. Discussion

It is clear that all of the most important innovations in Human-Computer Interaction have benefited from research at both corporate research labs and universities, much of it funded by the government. The conventional style of graphical user interfaces that use windows, icons, menus and a mouse and are in a phase of standardization, where almost everyone is using the same, standard technology and just making minute, incremental changes. Therefore, it is important that university, corporate, and government-supported research continue, so that we can develop the science and technology needed for the user interfaces of the future.

Another important argument in favor of HCI research in 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 out into products. Furthermore, without appropriate levels of funding of academic HCI research, there will be fewer PhD 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.

As computers get faster, more of the processing power is being devoted to the user interface. The interfaces of the future will use gesture recognition, speech recognition and generation, "intelligent agents," adaptive interfaces, video, and many other technologies now being investigated by research groups at universities and corporate labs [35]. It is imperative that this research continue and be well-supported.

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