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ARPA Does Windows: The Defense Underpinning of the PC Revolution

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ABSTRACT *The Defense Department's Advanced Research Projects Agency (ARPA) has aggressively and persistently supported technologies key to the personal computer (PC) revolution. Uncovering this political–economic link provides an important corrective to the popular lore surrounding the origins of the PC. In their emphases on private sector initiative and entrepreneurial risk-taking, conventional PC histories conform to orthodox market-based explanations of technological and economic progress. In contradistinction, this article "brings the state back in" to the PC realm of apparent market purity.*

1. Introduction[1]

> *The PC industry is leading our nation's economy into the 21st century ... There isn't an industry in America that is more creative, more alive and more competitive. And the amazing thing is all this happened without any government involvement.*
>
> Bill Gates (1998)[2]

The personal computer revolution, born out of risk-taking corporate ventures and garage-based innovative individualism, is the epitome of the heights than can be achieved by private-sector, free-market entrepreneurialism. While this is the conventional story, it is inaccurate. The personal computer (PC) technologies that have revolutionized our everyday lives, whether at the office or at home, have been deeply rooted in public sector initiatives as well. As communities throughout the country and countries around the world rush to clone their own Silicon Valleys, the governmental underpinnings of the original Valley's success should not be overlooked.

This story parallels the widely recognized government role in spurring a second revolution in information technology: the internet. The current-day internet traces its origins back, of course, to the late 1960s ARPANET project

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2. Microsoft News Release (1998). This statement was issued on the day the Justice Department launched its antitrust suit against the company.

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of the Defense Department.[3] However, when it comes to our main window on cyberspace—the personal computer—a defense or government link to such a ubiquitous business and consumer appliance is almost inconceivable. Instead, when it comes to the origins of what makes a PC a PC—its graphical user interface, windows, the desktop metaphor and icons, and the mouse pointing device—the genealogy is usually traced industrially through Apple and Microsoft and then back to the Xerox Palo Alto Research Center (or Xerox PARC for short). This accepted history is embodied in the mainstream business literature, general media, and popular culture.

What is less well known—and what serves as the focus of this article—is that Xerox PARC and other pioneers of PC technology were associated with a significant government-sponsored thrust in desktop computing. The Air Force, Army, Navy, NASA, National Science Foundation, and most notably, the U.S. Department of Defense's Advanced Research Projects Agency (ARPA or DARPA)[4] aggressively and persistently supported technologies key to the PC revolution.

Uncovering this political–economic link provides an important corrective to the popular lore surrounding the origins of the personal computer. In their emphases on private sector initiative and entrepreneurial risk-taking, conventional PC histories conform to orthodox market-based explanations of technological and economic progress. The role of government in spurring innovation and encouraging risk-taking is downplayed if not outright dismissed. This article brings the state back into the story of the development of the PC.[5]

In making this case, this article starts mid-story with the Xerox–Apple–Microsoft connection. Reflecting a balance in political–economic analysis, this portion of the article highlights the industry dimension of the PC's commercialization. The narrative then jumps back to the pre-Xerox, pre-commercialization story where the government role takes center stage. Before concluding, the penultimate section jumps ahead to discuss the government's, and particularly DARPA's, continuing influence on personal computing today and into the foreseeable future.

2. PARC and HCI

> *Xerox could have been the IBM of the 1990s ... could have been the Microsoft of the 1990s.*
>
> Steve Jobs (1996)[6]

3. The PC and networking stories do in fact intersect at important junctures in terms of personalities, private initiatives, and public policy. While certain references will be made to computer networking, this account focuses on advances in stand-alone computing. For the ARPANET story, see Reed, et al. (1990), chapter 20; Norberg and O'Neill (1996), chapter 4; Cerf (1993); Leiner, et al. (1997); Hart, et al. (1992); and Hafner and Lyon (1996).
4. The agency was founded in 1958 as ARPA, changed to DARPA ("Defense" added) in 1972, reverted back to ARPA in 1993, and then back to DARPA in 1995. The acronym used in this article will shift according to the time period under discussion.
5. Echoing the statist literature in political science and sociology. See Evans, et al. (1985).
6. "Triumph of the Nerds" (1996).

Microsoft Windows, the Macintosh, the mouse, the desktop metaphor with icons, file directories, and folders—indeed the very notion of computing at the individual, personal level—can all in the first (but not last) instance be traced directly back to the Xerox PARC Alto computer. The first two aforementioned systems were introduced in 1985 and 1984, respectively.[7] The Alto was completed in 1973.

Before tracing this genealogy, it would be appropriate to briefly demarcate our dependent variable, the personal computer. What the layperson calls a "personal computer" is, of course, an integration of myriad different technologies. A core subset of these technologies—and the core focus of this article—is what computer scientists call "human–computer interface" (HCI). HCI is concerned with enhancing the performance of joint tasks by humans and computers. To improve the structure of communication between human and machine, HCI brings together (1) the computer science and engineering fields of computer graphics, operating systems, programming languages, and software development; (2) behavioral science disciplines in communication theory, linguistics, learning theory, and cognitive psychology; and (3) graphic and industrial arts and design as well as ergonomics. Examples of HCI techniques include keyboard commands; pointing devices; touch screens and other display technologies; voice, handwriting, and gesture recognition; eye movement tracking; biological and psychic sensing; computer speech; graphical user interfaces; user navigation and menu selection tools; windows environments; and desktop metaphors.[8] Ultimately, from the user perspective, HCI technologies result in the user-friendliness and "look and feel"—or lack thereof—of our PCs.

HCI technology provided the crucial link between two other developments in the 1970s that ultimately produced the PC.[9] In a top-down development, the processing power of mainframe computers was slowly being brought to individual users through computer time-sharing.[10] The computer was still in the basement but scores of users could tap into its resources through remote terminals. While it represented a disservice to the mainframe's prowess, simple computer games such as Spacewar offered a glimpse of real-time interactive computing. Time-sharing, however, could reach only relatively limited numbers of users.

A second, bottom-up development of the 1970s would bring individualized computers to users but was handicapped with primitive features. Here we have the rise of computing devices cobbled together by and offered to electronics hobbyists and enthusiasts. While computers such as the Altair 8800

7. Windows 1.0 was introduced in 1985, but would not qualify as a fully functional graphical user interface. While version 1.0 and even version 2.0 had windows containing document contents, and while different programs could be open at the same time, the windows could not be overlapped (only tiled) and neither utilized graphical icons. Only with Windows 3.0 in 1990 would Microsoft offer a functional GUI. See Smithsonian Institution (1993).
8. Association for Computing Machinery (1992).
9. These two other developments are covered by Ceruzzi (1998), chapter 7.
10. Computer time-sharing, like the development of internet and HCI technologies, was initiated by government program, specifically by ARPA.

sat on a desktop, their interfaces were very rudimentary. To program the Altair, users had to flick a series of toggle switches for each program step. Hardly a model of interactivity, these machines had neither displays nor keyboards.

The first major effort to develop a broadly functional individualized computer with HCI-inspired interactivity and user-friendliness took place at the Xerox Palo Alto Research Center. PARC was established in 1970 to provide the technological undergirding for Xerox—the king of paper photocopying—to move into the "paperless" world of office computing. In the process, PARC became the premier draw for the country's best computer scientists—"like Disneyland for seven-year-olds."[11]

PARC's strategy centered on what it called "distributed interactive computing," and was embodied in the Alto office computer. The Alto was "distributed" in that it got the computer up from the basement and on to individual desktops. It was "interactive" both in the sense that Altos were to be networked with one another, and in their design for real-time responsiveness and user-friendly approachability for individual users.[12]

The Alto was intended for use by one individual with stand-alone processing power and memory. It was configured much like today's PC. It had a high-resolution monitor that could display a full-sized 8.5 by 11-inch page, a keyboard, a three-button mouse, a removable hard disk cartridge, and ports for printer and Ethernet connections. What today we would call the computer's tower was an Alto cabinet about the size of a portable refrigerator that can be found in today's college dorm rooms.[13]

The Alto's monitor was a key feature of its user interface. Beyond its full-page dimensions, the Alto monitor trumped the standard-of-the-day "character generator" displays—which, in typewriter spirit, would produce fully formed text characters in a preset font and color (usually green). Instead, the Alto could display high-resolution, user-defined fonts and graphics. Using now-standard "bit mapping" technology, the Alto could turn on and off half a million dots across its monitor—essentially turning everything on screen, including text, into pictures. Bit mapping also allowed the computer screen to display exactly what would be the output from a printer—a feature that is known as "what you see is what you get" or WYSIWYG.

The Alto's user friendliness is now taken for granted, but it was revolutionary in 1973.[14] Xerox designers began with the assumption that computer users were more interested in getting their work done than admiring the components of the computer itself. Therefore, an important Alto design principle was to make the computer as invisible and as intuitive as possible.

They chose a graphical user interface (GUI) for personal computing.[15] A graphically simulated office served as a working metaphor. Images on screen

11. Hiltzik (1999), p. 153.
12. Consistent with the HCI focus of this article, I do not elaborate on the networking aspects of the Alto.
13. A picture of the Alto can be seen at <http://www.archaic-apples.com/files/xerox/alto/altos.jpg>.
14. Smith, et al. (1982); Johnson, et al. (1989); and Miller and Johnson (1996).
15. A picture of the Xerox GUI can be seen at <http://www.sis.pitt.edu/~mbsclass/is2000/hall_of_fame/xerox.gif>.

represented the physical objects of an office—documents, folders, file cabinets, in-baskets, out-baskets, waste baskets, mailboxes, printers—all on an electronic rendition of a desktop. These images or icons could be manipulated with a mouse pointer to simulate the physical actions of opening, moving, filing, saving, deleting, and the like. The goal was to make everything needed visible on screen and subject to direct manipulation rather than requiring indirect and memory-taxing (not for the computer, but for humans) keystroke combinations.[16]

More than a decade before the Mac and Microsoft GUIs, the Alto had windows to display document contents. Multiple windows could be open at the same time, overlapped, and resized; documents could integrate text and graphics; and the windows had title bars, mouse-clickable command buttons, and scroll bars. The Alto had a full slate of applications for word processing, graphics (including animation), printing, email, and playing music. The Alto operating system even allowed for task-switching—the capability to easily and quickly switch between programs.

Nearly two thousand Altos were built and used by government, industry, and universities. A commercial version of the system, renamed the Xerox Star, was introduced in 1981—a full three and four years ahead of the Mac and Windows, respectively. The Star was marketed as "a new personal computer designed for offices … intended for business professionals who create, analyze, and distribute information."[17]

By current standards the Xerox interface did suffer from certain limitations. Commands such as "open," "copy," and "move" required a combination of mouse manipulations and special function key operations. Resizing windows and moving icons also required mouse and function key combinations. Menu bars were at the top of each window rather than a single set of menus at the top of the screen as a whole—resulting in the display of multiple and repetitive menu labels.

At the same time, and more significantly, the Alto suffered from being ahead of its time. While it was marketed as the dream machine for the "knowledge worker," such workers hardly existed in any real sense in 1981 let alone 1973.[18] And even if the market existed, the Alto was far from a marketable product—with each machine costing over $16,000 to build. The resulting commercial demise of the Alto and Star is legend in the business world. A popular recounting of this disaster was titled "Fumbling the Future: How Xerox Invented, Then Ignored, The First Personal Computer."[19]

16. Ironically, analysts have pointed out that Xerox pushed the physical desktop metaphor *too far*—requiring cumbersome mouse manipulations where simple keyboard commands would have been sufficient (e.g., requiring that a document icon be moved over a printer icon instead of a simple key command for printing). Miller and Johnson (1996), p. 93.
17. Smith, et al. (1982), p. 653.
18. Baecker and Buxton (1987). Even the Xerox sales force had difficulty "getting it." Upon the conclusion of an Alto demonstration, one brave soul asked, "Where's the click?" Hiltzik (1999), p. 393.
19. Smith and Alexander (1988). For PARC's commercial fate, see also Hiltzik (1999).

3. Alto's offspring

> *When Apple sued Microsoft in 1988 for stealing the "look and feel" of its Macintosh graphical display to use in Windows, Bill Gates' defense was essentially that both companies had stolen it from Xerox.*
>
> Michael Hiltzik[20]

Xerox "fumbling its future" does not mean that its technologies were commercial failures. Indeed, many of the PARC and Alto technologies were in fact successfully commercialized—but just not by Xerox. For instance, outside of the HCI area, notable PARC alumni developed market blockbusters out of their Xerox work:

- Bob Metcalfe brought his Ethernet work to market by founding 3Com.
- Chuck Geschke and John Warnock commercialized the computer rendering of graphics for laser printing by cofounding Adobe Systems.
- Edwin Catmull and Alvy Ray Smith took their computer animation work first to Lucasfilm and then cofounded Pixar—making the *Star Trek* and *Toy Story* movies, among others, along the way

When it comes to HCI technology, the Xerox legacy and progeny is even greater. In particular, the transfer of technology and, even more importantly, the transfer of people from PARC has been crucial to developments at both Apple and Microsoft.[21]

Apple's day in the PARC

The flip side of Xerox's fumbling the PC's future is the Macintosh story, which began when Steve Jobs, Apple's CEO, took a tour of Xerox PARC in December 1979. In 1979, Apple was concerned it would soon lose its first mover advantage in the PC industry. Apple employee Jeff Raskin suggested that Xerox PARC held the keys for Apple's future. In the early 1970s, Raskin had spent considerable time at PARC while he was a visiting scholar at Stanford's Artificial Intelligence Laboratory.[22] After Apple arranged for Xerox to purchase $1 million of Apple's skyrocketing shares, PARC agreed to show Apple the Alto.

The Alto team made not one, but two presentations—and not just to Jobs, but to a dozen of Apple's leading executives and programmers. Upon seeing the Alto, Apple software designer Bruce Daniels declared, "That's it—that's what we want to build."[23] While no "blueprints" were transferred, Apple came away from these sessions with a vision of the future of personal computing, and eventually key members of the PARC team.

20. Hiltzik (1999), p. xxv. Bill Gates has remarked: "Hey, Steve, just because you broke into Xerox's house before I did and took the TV doesn't mean I can't go in later and take the stereo." *MacWeek*, 14 March 1989, p. 1.
21. Other Alto-inspired GUI efforts not covered in this article include those by Digital Research, IBM, and VisiCalc—efforts that did not match the success of the Mac or Windows.
22. Jeff Raskin correspondence, <http://www2.h-net.msu.edu/~mac/lore2.html>; Linzmayer (1999), p. 52.
23. "The Birth of the Lisa," *Personal Computing*, February 1983, p. 89; Levy (1994), chapter 4.

The Xerox visit first inspired the development of the Lisa computer system, the Apple computer that immediately preceded the Macintosh. The Lisa was in development before the Xerox visit, but it was slated to have a non-graphical user interface and a non-bit mapped character-generator display. It also did not have a mouse. All this changed after the Xerox visit. In the words of Apple executive Larry Tesler, the Lisa was "completely redefined ... only the code name, some of the hardware components, and a few of the staff members stayed the same." From the Alto, the Lisa would directly borrow the desktop metaphor, pop-up menus, overlapping windows, and scroll bars. After the 1981 introduction of the Xerox Star, the Lisa team made further changes to their GUI including the incorporation of desktop icons. On Apple's part, the Lisa would be the first to introduce the menu bar at the top to the screen (instead of menus atop each window), the one-button mouse, pull-down menus (point-and-drag mouse movement), and icons that could be dragged with the mouse and double-clicked to open.[24]

Like the Alto, the Lisa was a commercial failure when it was introduced in January 1983. But its graphical user interface was transferred directly into the Macintosh. Indeed, PARC-savvy Jeff Raskin had begun development of the Mac in the spring of 1979. After the Xerox visit, Raskin added the mouse to the Mac.[25] Beginning in January 1982, key members of the Alto-inspired Lisa team were transferred to the Macintosh division. Lisa software programs for word processing and graphics (LisaWrite, LisaDraw) would be converted to the Mac (MacWrite, MacDraw). The two product teams were completely merged in November 1983, and the Mac was introduced January 1984.[26]

Besides inspiration, the Xerox influence on Apple took on a second major form: the transfer of key PARC personnel to Apple. PARC alumni Alan Kay and Larry Tesler were two of the major coups for Apple. Alan Kay was PARC's chief evangelist for personal computing. In his 1969 dissertation, Kay outlined a Dynabook—a computer the size of a notebook with an 8 by 10-inch flat screen and integrated keyboard that was only two inches thick and weighed only two pounds. He had essentially envisioned today's laptop computer.

For the Alto, which he viewed as an "interim Dynabook," Kay led the development of its overlapping windows capability. The Alto not only allowed users to work in and see more than one window at a time, but it was the first system that allowed windows to be resized and moved—including over one another. This overlapping capability was a major advance over the preexisting standard of tiled multiple windows that were fixed in place, and virtually expanded the working space of a computer monitor. Kay also inspired the Alto's pop-up menus—where the click of one of the mouse's buttons would cause menu options to appear on screen from which a command (e.g., paste) could be selected.[27]

24. Linzmayer (1999), pp. 54–56; Miller and Johnson (1996), p. 94; Larry Tesler, "The Legacy of the Lisa," *Macworld* (September 1985); "The Birth of the Lisa," pp. 88–94.
25. Ceruzzi (1998), p. 273.
26. Tesler, "The Legacy of the Lisa;" Linzmayer (1999), pp. 57–75.
27. Hiltzik (1999), pp. 224–228.

In 1980, Kay became chief scientist at Atari where he applied his HCI visions to interactive gaming. In 1984 be became an Apple Fellow, and inspired the company's successful PowerBook laptop computer line, and the Newton—the industry's first personal digital assistant (PDA) and forerunner to the Palm Pilot and other handheld computing devices. Since 1996, Kay has been a Disney Fellow and Vice President of Research and Development at the Walt Disney Company.

Larry Tesler preceded Kay in moving from Xerox to Apple. Tesler worked in Kay's section of PARC where he was dedicated to making computing more intelligible to the average user. For the Alto, Tesler designed Gypsy, a powerful word processing program that employed a graphical user interface with extensive icons and menus. In Gypsy, the mouse could point to and select blocks of text, whereas previous applications only used the mouse to position the cursor and called for keyboard commands for text selection. As an illustration of its user friendliness, Gypsy was the first program to replace commands for deleting a block of text and then placing it elsewhere with the simple labels of "cut" and "paste."[28]

In December 1979 Tesler was one of the two major presenters of the Alto to Steve Jobs and company. In July 1980 he would move to Apple. Tesler first headed up the Lisa user interface team, then helped design the Macintosh including its one-button mouse, and then led the Newton PDA development team. He eventually rose to the position of Vice President and Chief Scientist before leaving Apple in 1998 to found a software startup.

Kay and Tesler were not alone in making the move from Palo Alto to Cupertino, where Apple is headquartered. For instance, Dan Ingalls—Kay's right hand man and coauthor of one of the Alto's operating system—would follow Kay to Apple. Tom Malloy, who worked on word processing programs for the Alto, would go on to Apple and write the word processor for the Lisa (LisaWrite). Former Xerox PARCers Bruce Horn and Steve Capps would cowrite the Macintosh Finder, its graphical file directory. Altogether, some fifteen PARC alumni would make the move to Apple.[29]

Microsoft's window on Xerox

While the Xerox-Apple story is better known, Microsoft was also a major beneficiary of PARC's work. First, Microsoft Windows drew directly from the Alto-inspired Macintosh. Not unlike Jobs' 1979 visit to Xerox, Microsoft CEO Bill Gates visited Apple in 1981. There he saw a Mac prototype, and immediately thereafter began development of Microsoft's GUI, Windows. In 1982, Mac prototypes were delivered to Microsoft for the software company to develop Word and Excel for the new machine. At the same time, the prototypes were used to guide the development of Windows.

This Mac influence would show up even when Gates expressed dissatisfaction at Windows' early development. The Microsoft CEO would complain: "That's

28. Hiltzik (1999), pp. 201–203, 207–210.
29. Hiltzik (1999), pp. 214–215, 217–218. 316–317; Miller and Johnson (1996), p. 76; Linzmayer (1999), p. 54.

not what a Mac does. I want Mac on the PC, I want a Mac on the PC."[30] To correct the situation, Gates transferred his resident "Macintosh wizard," Neil Konzen, to the Windows team. Having developed Microsoft's initial applications for the Mac, Konzen rewrote much of the Windows code by emulating the Mac's internal structure. The results, in Konzen's words, were "Mac knockoffs." Even certain Mac system errors were carried over to the Windows platform.[31]

While the Mac served as a go-between for Xerox's influence on Microsoft, there were direct Xerox–Microsoft connections as well. To begin with, Gates got his tour of PARC and an Alto demonstration in 1980. Soon thereafter, Microsoft purchased a Xerox Star, the commercial version of the Alto. Microsoft did not intend to put the machine to operational use. Instead, in the words of one of Microsoft's leading programmers, "we just wanted everybody in the organization to get used to the desktop and to the mouse … we used it for education of the people."[32]

That programmer was Charles Simonyi, who embodied yet another type of Xerox influence on Microsoft: PARC alums who moved from Palo Alto to Bellevue and Redmond, Washington, where Microsoft has been headquartered. At PARC, Simonyi cowrote the Alto's "killer app"—Bravo, its first word processor. Bravo was the first program that could insert text in the middle of a document, display fancy typefaces, number pages, format odd margins, and print almost exactly what was on screen,[33] and it served as the basis for Tesler's Gypsy word processor.

Not unlike Larry Tesler's 1979 presentation to Steve Jobs and subsequent move to Apple, it was Simonyi who demonstrated the Alto to Gates in November 1980 and subsequently moved to Microsoft in February 1981. Joining as Microsoft's fortieth employee, Simonyi essentially "brought Microsoft Word with him."[34] According to Gates, Simonyi was specifically brought "on board to help us write applications that would eventually become very graphical,"[35] and Simonyi characterized his mandate as to spread the "PARC virus" in Bellevue.[36] As director of advanced product development, Simonyi hired and managed the teams developing the entire suite of Microsoft applications, including Excel and PowerPoint as well as Word. Simonyi is one of the "seven software samauri" to whom Gates turns for advice, and has been a member of the Executive Committee, the company's most senior-level decisionmaking team.[37] When

30. Campbell-Kelly and Aspray (1996); Linzmayer (1999), p. 136. For views of the early Windows interface, see <http://pla-netx.com/linebackn/guis/win1983.html>.

31. Wallace and Erickson (1992), pp. 221, 273–274. While corporate rivalry has inhibited prominent personnel transfers between the two companies, some members of the Mac team would move on to Microsoft. For instance, Susan Kare did graphic design work for Windows 3.0 after designing the first icons, typefaces, and other graphics for the Macintosh. "The New Face of Open Source OS?" *MacWeek*, 21 February 2000; Linzmayer (1999), p. 73.

32. Edge Foundation.

33. Hiltzik (1999), pp. 198–200, 358–360.

34. Hiltzik (1999), p. 395; Miller and Johnson (1996), p. 76.

35. Smithsonian Institution (1993).

36. Edge Foundation.

37. Wallace and Erickson (1992), p. 369.

Microsoft's Research Division was established in 1991, Simonyi became its Chief Architect.

While Bill Gates hired Simonyi to lead the development of the graphically oriented Microsoft Office Suite, he tapped a second PARC computer scientist, Scott MacGregor, to lead the development of the Windows operating system. At PARC, MacGregor oversaw development of the Xerox Star's windowing system. In summer 1983, Gates recruited MacGregor to be head of the Windows engineering team. In MacGregor's words, "Microsoft was looking for somebody who had done this thing before. They didn't want to reinvent the wheel. That's why they went shopping at Xerox." In that shopping spree, Microsoft would hire others such as Dan Lipkie, a Xerox programmer who would work on Word as well as Windows.[38]

Microsoft's Research Division is the site of Xerox's continuing influence on the software company. At the Microsoft labs, Simonyi has been joined by four other of PARC's leading lights: Chuck Thacker, Butler Lampson, Gary Starkweather, and Alvy Ray Smith.[39] Thacker, the lab's Director of Advanced Systems, was the chief designer of the Xerox Alto. He championed the Alto's high-resolution, bit-mapped display over the monochrome green monitors of the day, and he designed the Star's first central processor. Lampson, now a Microsoft Distinguished Engineer, first conceived and started work on Alto's Bravo word processor—work that Simonyi would later continue. Lampson also designed the second central processor for the Star. Starkweather developed the Alto's laser printer and, in the process, launched a whole new industry: desktop publishing. Smith, a Microsoft Fellow until 1999, wrote the Alto's graphics program. Before joining Microsoft, Smith would design for Lucasfilm, cofound Pixar, and win two technical Academy Awards. For Microsoft, these PARC alumni have worked on advanced programming and graphics, hand-held and wireless computing devices, and computer security.

Xerox's legacy extends, of course, well beyond Apple and Microsoft. Its current-day manifestations are innumerable, but two in particular merit mention. Akin to Alan Kay's move from Xerox to Atari (before moving on the Apple), HCI advances have been a key driving force behind the interactive gaming industry, with applications ranging from game consoles and joysticks to virtual reality environments. And the World Wide Web, which began with text-based interfaces like Gopher, exploded in popularity only after user-friendly graphical user interfaces were employed by the Mosaic and Netscape web browsers.

Even without a more comprehensive assessment of Xerox's legacy (a project worthy of an entire piece on its own), its import should not be in doubt. That import sets the proper perspective for considering the R&D that preceded and led into Xerox's effort—a task to which we now turn.

38. Wallace and Erickson (1992), pp. 253–255.
39. Hiltzik (1999), pp. 397–398.

4. The rest of the story

> *Silicon Valley. The World Wide Web. Wherever you look in the information age, Vannevar Bush was there first.*
>
> *Wired Magazine* (November 1997)[40]

> *The Alto system grew from a vision of the possibilities inherent in computing: that computers can be used as tools to help people think and communicate. This vision began with Licklider's dream of man-computer symbiosis.*
>
> Butler Lampson, Xerox PARC (1986)[41]

> *Ivan Sutherland's Sketchpad program is one of the most significant developments in human-computer communication.*
>
> Transforming Computer Technology (1996)[42]

While the commercial ramifications of Xerox PARC's work cannot be overemphasized, Xerox was not the sole source of the HCI revolution. Just as Apple and Microsoft drew upon Xerox, so too was Xerox the beneficiary of the prior work of others.

While the narrative thus far has been heavily industry-oriented, what follows is the non-business dimension of the PC's development. Most of the innovations *and* people discussed thus far were in fact influenced by government-sponsored initiatives. Those initiatives began with Vannevar Bush, J.C.R. Licklider, and Ivan Sutherland.

Vannevar Bush

The *Online Encyclopedia Britannica* entry for "graphical user interface" reads: "There was no one inventor of the GUI; it evolved with the help of a series of innovators, each improving on a predecessor's work. The first theorist was Vannevar Bush."[43] The source of this attribution was Bush's vision of a "memex,"

> in which an individual stores all his books, records, and communications … It consists of a desk … On the top are slanting translucent screens, on which material can be projected for convenient reading. There is a keyboard, and sets of buttons and levers … if the user inserted five thousand pages of material a day it would take him hundreds of years to fill the repository … If the user wishes to consult a certain book, he taps its code on the keyboard, and the title page of the book promptly appears before him, projected onto one of his viewing positions … [with] one of the levers to the right he runs through the book before him, each page in turn being projected at a speed which just allows a

40. G. Pascal Zachary, "The Godfather," *Wired*, November 1997, p. 152.
41. Lampson (1988), p. 293.
42. Norberg and O'Neill (1996), p. 36.
43. Encyclopedia Britannica Online.

> recognizing glance at each. If he deflects it further to the right, he steps through the book ten pages at a time; still further at one hundred pages at a time. Deflection to the left gives him the same control backwards … he can leave one item in position while he calls up another.

Bush went on to consider the memex's applications:

> The lawyer has at his touch the associated opinions and decisions of his whole experience, and of the experience of friends and authorities. The patent attorney has on call the millions of issued patents, with familiar trails to every point of his client's interest. The physician, puzzled by its patient's reactions, strikes the trail established in studying an earlier similar case, and runs rapidly through analogous case histories, with side references to the classics for the pertinent anatomy and histology. The chemist, struggling with the synthesis of an organic compound, has all the chemical literature before him in his laboratory, with trails following the analogies of compounds, and side trails to their physical and chemical behavior.[44]

This vision of the memex is widely recognized in government, industry, and academic circles as the first major articulation of the modern personal computer, including hypertext and internet links. Xerox-Apple alumnus Alan Kay observes that "Bush's vision of a hyperlinked, ten thousand volume library in a desk had a great impact on the development of personal computing."[45] Tim Berners-Lee, inventor of the World Wide Web, notes that "to a large part we have Memexes on our desks today."[46]

The memex was not the product of a science fiction writer conjuring up visions of the future; nor an entrepreneur toiling away on a garage workbench; nor an industrial researcher supported by a well-financed corporate laboratory. Instead, Vannevar Bush was a government official. More specifically, he was the Director of the Office of Scientific Research and Development—the chief science advisor to the President of the United States. When Bush envisioned the memex, the President was Harry Truman; the date July 1945.

Between 1941 and 1947, Vannevar Bush served as science advisor to both Franklin Roosevelt and Harry Truman. His greatest contribution in office is highly debatable in both the best and worst of senses. First, he organized the six thousand-strong scientific enterprise to help prosecute the U.S. war effort. While he was not physically in the sands of New Mexico, Bush oversaw the Manhattan Project to create the first atomic bomb. Second, he established the structure of the country's postwar science and technology effort—including the prominent roles played by military R&D, the National Science Foundation, and university-based research.[47]

44. Vannevar Bush, "As We May Think," *Atlantic Monthly*, July 1945.
45. Kay (1995).
46. Berners-Lee (1995).
47. Zachary (1997).

Then there is the memex. Bush's vision inspired R&D efforts throughout government, industry, and academia. The lead player in this R&D was the Advanced Research Projects Agency (ARPA).

J.C.R. Licklider

Since its inception in 1958, ARPA has supported both the development of military-specific weapons technologies as well as more generic technologies with the potential for military application. The former included ballistic missile defense and tactical antitank weapons technologies, and even the M-16 rifle. The latter includes R&D in new materials, novel energy sources, and biomedical technologies as well as computer science.

ARPA began its computer science work in 1962 when it established its Information Processing Techniques Office (IPTO) as one of a half-dozen technology-specific offices within the agency.[48] Starting off with a $7 million annual budget, IPTO's funding was larger than the computer research budgets of the rest of the government combined. Over the next eight years, the IPTO budget would more than quadruple.

Most of IPTO's funding went to university research. It is hard to imagine now, but before 1962 no formal university computer science programs existed. ARPA's IPTO grants were crucial in establishing the country's first graduate programs in computer science, including those at MIT, Stanford, Berkeley, Utah, and Carnegie Mellon.[49]

J.C.R. Licklider was the ARPA official that served as the guiding light behind this effort. As quoted above by Xerox PARCer Butler Lampson, the Alto would grow out of Licklider's vision. Licklider was IPTO's inaugural director from 1962 to 1964. Earlier, as an MIT professor, Licklider "got fired up about the idea Vannevar Bush had mentioned in 1945, the concept of a new kind of library to fit the world's new knowledge system." Licklider's 1959 book, *Libraries of the Future*, was not only dedicated to Bush but expanded upon the memex concept. When he moved on to ARPA, he brought with him his "religious conversion" to interactive computing.[50]

From ARPA, Licklider galvanized the computing research community around two pathbreaking concepts. Given the first one—"the intergalactic network"—it is almost understandable to overlook the second. The intergalactic network was "the first concrete proposal for establishing a geographically distributed network of computers."[51] As initiated by Licklider, the network would first take the form of computer time-sharing links and later transform into the ARPANET/internet.

As consequential as this first concept has been, the second—"man-computer symbiosis"—is arguably just as profound. Licklider came to computing not as a computer scientist, but as an academic psychologist. His interest was in how

48. IPTO has undergone a number of name changes over the past forty years, and is currently named Information Technology Office (ITO).
49. Norberg and O'Neill (1996).
50. Rheingold (1985), chapter 7.
51. Campbell-Kelly and Aspray (1996), p. 288

computers could contribute to, rather than replace, human cognitive processes. He was concerned that the rudimentary user interfaces of computers of the 1950s hindered the technology's true potential. To realize that potential, he called for computing advances in real-time processing and interactivity. He called for advances in the computer's outward face to its user—its display—and in how users input instructions into the computer, including via graphical input and automatic speech recognition. In calling for a "much tighter coupling between man and machine," Licklider sought to realize "interaction with a computer in the same way that you think with a colleague whose competence supplements your own."[52]

These are all matters of human–computer interface, and Licklider defined the HCI agenda for decades to come. ARPA-supported research universities not only took part in building Licklider's "intergalactic network," but they launched major HCI initiatives as well.[53]

Ivan Sutherland

When Licklider prepared to leave ARPA in 1964, he selected Ivan Sutherland to replace him as IPTO director. Sutherland was one of the first researchers to take up Licklider's HCI challenge. His 1962 Ph.D. project at MIT, called Sketchpad, was the first-ever computer graphics program where the user could make drawings on screen interactively.

Sketchpad is widely recognized as the seminal program that started off the entire field of computer graphics.[54] But Sutherland's immediate motivation was to advance human–computer interactivity. Indeed, the subtitle of his project was "A Man–Machine Graphical Communication System."[55] Three features made Sketchpad, as quoted above, "one of the most significant developments in human-computer communication."

First, Sketchpad was one of the first computers with a monitor, and a user's work would immediately be represented on screen. This form of interactivity is now easy to take for granted, but before Sketchpad users would have to wait for a printout in order to see their work.[56]

Second, Sketchpad was one of the first computers to use a pointing device. A hand-held "light pen" was employed to make drawings. The pen would make physical contact with the screen and its "light" would be picked up by the computer. Moving the pen would draw lines on screen in real-time. The pen could also be used to grab-and-drag images as well as rotate, expand, or contract an image. This was a major user interface breakthrough: before Sketchpad users had to express object geometry by typing coordinates on a keyboard. The light pen would later lead to today's mouse.

52. Licklider (1960).
53. More on Licklider can be found in Waldrop (2001).
54. Wolfe (1998).
55. Sutherland (1963). See also Norberg and O'Neill (1996), pp. 125–128.
56. Wolfe (1998).

Third, Sketchpad was the first system with a rudimentary windowing system. The Sketchpad screen could be split to produce two work areas or windows. One section could, for example, display a close-up view of an object in the other section.[57]

The Sketchpad project was sponsored by the Army, Navy, and Air Force. This funding is a reminder that government agencies other than ARPA have also supported HCI technology. In this particular case, the three military services provided support to Sutherland before IPTO was even established.

Licklider hired Sutherland to explicitly carry on IPTO's HCI work. As IPTO director, Sutherland would fund major university programs in computer graphics. Besides fueling the burgeoning field of computer generated images, this research would provide the foundation for computers with "graphical" user interfaces, "picture" icons, and high-resolution bit-mapped displays. Such displays, interfaces, and icons along with Sketchpad-derived windows and pointing devices would be incorporated into the Xerox Alto.

5. Xerox's ARPA brats

> *Xerox PARC was set up near the Stanford campus. For the next ten years the ARPA dream took up residence at PARC.*
>
> Frank Rose[58]

A veritable "ARPA Army"—a phrase coined at PARC—would fill the ranks of computer scientists at the Xerox. This influx into Xerox was led not by a researcher from an ARPA-supported university, but by an official direct from ARPA itself, Robert Taylor. J.C.R. Licklider had not only selected Ivan Sutherland to replace him as director of IPTO, but chose Robert Taylor to be associate director. When Sutherland finished his term as director in 1966, Taylor took his place, serving through 1969.

Robert Taylor "heartily subscribed" to Licklider's vision of computing even before joining ARPA.[59] In his first year in office, he advanced Licklider's "intergalactic network," transforming it from a computing time-sharing paradigm to a decentralized packet-switching network, the ARPANET. While ARPANET's construction would begin under Taylor's successor at IPTO, Lawrence Roberts, the network's design was completed under Taylor.

Taylor was also a true believer in Licklider's theme of "man–computer symbiosis." Taylor held a NASA research post in HCI just prior to joining ARPA, and distributed interactive computing became his "sacred cause" as director of IPTO.[60] As described in a 1968 paper coauthored with Licklider, Taylor envisioned a computer for each individual user; each had a large television monitor, a keyboard, and "electronic pointer controllers called 'mice' [that could] control the movements of a tracking pointer on the TV screen."[61]

57. "Of Mice and Menus" (1989), pp. 48–49.
58. Rose (1989), p. 45.
59. Norberg and O'Neill (1996), p. 29.
60. Hiltzik (1999), p. 19.
61. Licklider and Taylor (1968).

This vision grew directly out of the memex of Vannevar Bush, and presaged Xerox PARC's Alto.

When Xerox started forming its PARC facility in 1970, one of the first people they tapped was Robert Taylor. He has been called "the impresario of computer science at Xerox PARC,"[62] and described as playing "the Robert Oppenheimer role"—making a parallel to the noted director of the Manhattan project.[63] Taylor exercised this influence as head of the Computer Science Laboratory (CSL)—the largest of PARC's four internal labs. It was CSL that would become the mecca for fifty of the country's top computer scientists.

In the spring of 1971, Taylor set CSL's agenda by proposing that it build the machine he had written about in 1968. He even gave the machine its "Alto" name. And to build it, Taylor recruited his researchers largely from ARPA-funded research centers. Indeed, he chose researchers who he, Licklider, and Sutherland had directly and personally supported through IPTO.

ARPA's army

Stanford, Berkeley, Utah, and the Stanford Research Institute (SRI) were the major programs from which Taylor drew. Most of these researchers—and their exploits at Xerox, Apple, and/or Microsoft—have already been noted in the first half of this article. Here we reveal their university and ARPA pedigrees. To help keep the names and affiliations straight, Figure 1 graphically displays some of these people and places.

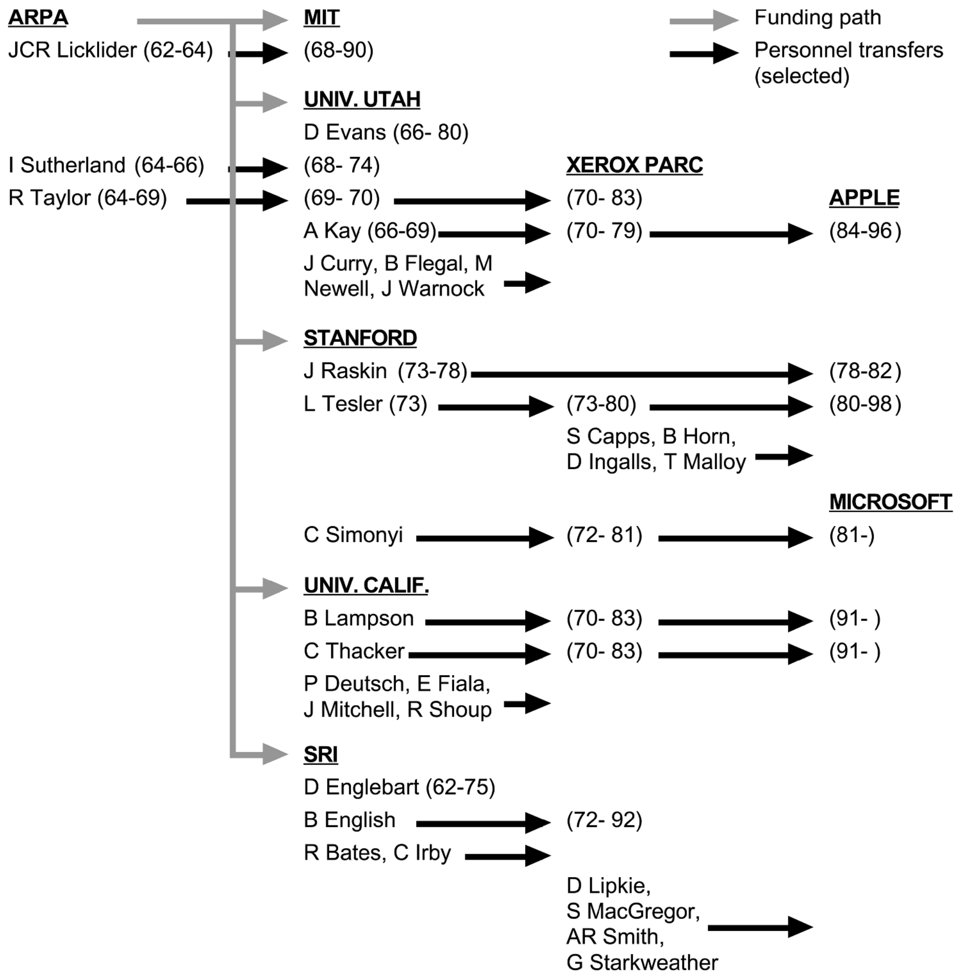
Stanford's Artificial Intelligence Laboratory was established in 1962 with ARPA funding. Indeed, into the 1970s most if not all of the computing research conducted at Stanford would be supported by ARPA—as would be the case at Berkeley, Carnegie Mellon, Illinois, MIT, UCLA, and Utah.[64] Out of Stanford, Taylor hired Larry Tesler and Charles Simonyi, who would later go on to Apple and Microsoft fame, respectively.

In 1963, IPTO began supporting Project Genie at Berkeley, a small-scale computer time-sharing project. Charles Thacker and Butler Lampson as well as Simonyi from Stanford would first come together to work on this project and its commercial spinoff, the Berkeley Computer Corporation.[65] While burdened by the mainframe paradigm, this experience sparked their pursuit of interactive computing. The three were considered among the country's top programmers, and Taylor hired them as a group to join PARC in 1970. Taylor would hire others from Berkeley including Peter Deutsch, Ed Fiala, Jim Mitchell, and Dick Shoup. Thacker, Lampson, and Simonyi would all end up at Microsoft.

One of the Berkeley faculty members that directed Project Genie, David Evans, would not go to Xerox. Instead he remained in academia training students, many of whom would make the trek to PARC. This is the Utah connection, where Evans became head of the computer science department in

62. Hiltzik (1999), p. 3.
63. *Forbes ASAP*, 7 October 1996.
64. Norberg and O'Neill (1996), p. 290.
65. Norberg and O'Neill (1996), pp. 102–103; Hiltzik (1999), pp. 18–19, 68–78.

FIGURE 1. From ARPA to Windows.



1966. As IPTO director, Taylor would make a $5 million award to Evans to transform Utah into a center of excellence for computer graphics.[66] Ivan Sutherland, Taylor's predecessor and creator of the Sketchpad program, would be on the Utah faculty from 1968 to 1973. Taylor himself would spend a year at Utah between his ARPA and PARC tenures.

Taylor would bring to CSL many Utah students, including Jim Curry, Bob Flegal, Martin Newell, and John Warnock. But the key hire for the Alto and HCI at Xerox was Alan Kay in 1972. Kay came to Utah in 1966 as one of Evans' first graduate students. At their very first meeting, Evans asked Kay to read Sutherland's Sketchpad dissertation. In a reaction any professor would die for, Kay has described his reading of Sketchpad as "seeing a glimpse of heaven."[67]

66. Norberg and O'Neill (1996), pp. 137–143.
67. Hiltzik (1999), p. 91.

Kay would try to capture a bit of that heaven first in his own dissertation, then at PARC, and later at Apple.

One of the major ARPA-supported research centers that has yet to be mentioned, and that has made major contributions to the PC industry, is the think tank Stanford Research Institute. SRI was the home of computer scientist Douglas Engelbart from 1957 to 1975. Engelbart was inspired by Licklider's notion of augmenting (rather than replacing) human intellect via "man–computer symbiosis." Indeed, Engelbart's lab at SRI was called the Augmentation Research Center.[68]

In designing a system to augment human intelligence, Engelbart used Vannevar Bush's memex concept as an ideal type.[69] Over a two-decade period, Engelbart would develop a computerized personal information storage and retrieval system to replace paper and hardcopy filing systems. Called NLS (for oN Line System), the system was not a personal computer, but rather a networked workstation. It had a large video monitor and input devices to manipulate information on screen, but it was all cabled into a remote mainframe computer.[70]

Still, NLS made two major contributions to "man–computer symbiosis" and HCI. First, it advanced windowing capabilities by being able to divide the display screen into four work areas—an improvement over the split-screen capability of Ivan Sutherland's Sketchpad system. The user could now easily shift work from one window to another.[71] Second, NLS introduced a new pointing device to move a cursor within and between document windows. Engelbart conducted a series of studies comparing various pointing devices including Sketchpad's light pen, track balls, joysticks, and even a knee-switch under the desktop.[72] What he decided upon was a device that "stays put when your hand leaves it do something else (type or move a paper) and reaccessing [it] proves quick and free from fumbling … and it doesn't require a special and hard-to-move work surface."[73] This device is, of course, the mouse. Initially the size of a brick and carved out of a block of wood, the underside of Engelbart's mouse had two wheels positioned at right angles to one another that could digitally track and convey its position to the computer.[74] While the wheels would be replaced with a ball, the computer mouse was not invented by Xerox in 1973, let alone Apple in 1984. It was created by Engelbart in 1964.

The system described earlier in Robert Taylor's 1968 paper—a large video screen, keyboard, and a mouse—was Engelbart's NLS. Not only did Taylor properly cite Engelbart in that paper, but Engelbart had three major connections to Taylor and ARPA.

68. Bootstrap Institute; Hiltzik (1999), p. 63.
69. Rheingold (1985), p. 260.
70. A picture of the Engelbart system can be seen at <http://www.bootstrap.org/chronicle/hist_pix/img0024.jpg>.
71. "Of Mice and Menus" (1989), p. 49.
72. English, et al. (1967).
73. Levy (1994), p. 41.
74. A picture of the Engelbart mouse can be seen at <http://www.p2pr.com/Image1.GIF>.

To begin with, Taylor—while at NASA—provided initial funding for Engelbart's project. The Air Force did as well. Both NASA and the Air Force were interested in how operators in their command centers could best interface with their computers.[75] As in the case of Sutherland's Sketchpad project, Engelbart received support from these other organizations before IPTO was even established.

Then, with IPTO's establishment in 1962, "Douglas Engelbart was one of the first persons to apply for funding."[76] Not only did he gain IPTO funding, but the support would significantly rise during Taylor's tenure. ARPA funding would continue until 1975, and Engelbart's research team would expand from two to nearly fifty. In 1968, ARPA and NASA cosponsored a major presentation of the NLS to the public that amazed the wider computing research community.

Then there is the Xerox connection. In the words of Butler Lampson, the NLS "made a profound impression on many of the people who later developed the Alto."[77] Both the mouse and windows were directly incorporated from NLS into the Xerox computer.

Moreover, Taylor hired key members of the NLS team to come to PARC. Akin to David Evans remaining at Utah, Engelbart would not himself make the move to Xerox. But Taylor did hire Engelbart's right hand man, Bill English. English was NLS's hardware expert and had done the detailed design work on the mouse. Taylor offered English the chance to "reproduce NLS, or something like it, at PARC."[78] Another member of the NLS team, Roger Bates, would help develop the Alto's high-resolution bit-mapped display. NLS alumnus Charles Irby would help design the user interface for the Xerox Star. Altogether, a dozen of Engelbart's team would make the move to PARC.[79] Given these hires from SRI and the universities, ARPA-supported research would leave an "indelible stamp on almost every major innovation to emerge from PARC."[80]

Beyond ARPA's influence on Xerox, it is difficult not to mention other major computer scientists that have been supported by IPTO—including Wesley Clark, Lynn Conway, Michael Dertouzos, Edward Feigenbaum, John Hennessy, Daniel Hillis, John McCarthy, Carver Mead, Marvin Minsky, Alan Newell, David Patterson, and Raj Reddy. Then there are those that have left their mark in the commercial world. We have already mentioned Bob Metcalfe of 3COM, John Warnock of Adobe Systems, and Edwin Catmull of Lucasfilm and Pixar—all of whom came out of PARC. We can now note their earlier ARPA-backing at Harvard and Utah (last two). To this list we can add Nolan Bushnell (Utah), founder of Atari; Jim Clark (Utah), cofounder of Silicon Graphics and Netscape; and Bill Joy (Berkeley), cofounder of Sun Microsystems.[81]

75. Norberg and O'Neill (1996), p. 131.
76. Ceruzzi (1998), p. 260.
77. Lampson (1988), p. 294.
78. Hiltzik (1999), p. 67; Ceruzzi (1998), p. 260.
79. Hiltzik (1999), p. 173; "The Mouse."
80. Hiltzik (1999), p. 67.
81. See Computing Research Association (1997); National Research Council (1995), chapter 1; and Norberg and O'Neill (1996).

But our focus here has been on HCI-specific ARPA-supported researchers who made their way to Xerox PARC and then contributed to or influenced developments at Apple or Microsoft. Even with these restrictors, the ARPA reach is substantial. "ARPA does Windows" is more than a catch phrase.

6. Windows on the future

The story has now come full circle. Vannevar Bush's extraordinary vision is followed up by ARPA's Licklider, Sutherland, and Taylor. They sponsor the Stanfords, Berkeleys, Utahs, and SRIs. Xerox draws upon this research and the researchers (plus Taylor). Then Apple and Microsoft commercialize Xerox's work. The rest, as they say, is history.

But the PC revolution does not stop with Windows. And ARPA's hand in matters HCI is not confined just to decades past. Indeed, ARPA's and other government agencies' support for further advances in personal computing continues to this day.

A high-level conference sponsored by Intel in March 2000 illustrates this continuing influence. Five hundred of the world's leading computer scientists came together for Intel's Computing Continuum Conference to "define the next era of computing, communication, and interaction in the digital world."[82] Three dozen "visionaries" made presentations on topics ranging from artificial intelligence to ubiquitous networked computing. Table 1 lists the five presentations that were organized for a panel explicitly on HCI.

The primary sponsors of this leading-edge HCI research are identified. Seven sponsors are government agencies (including the European Union), and three are industry. Significantly, DARPA is a sponsor in four of the five cases; followed by National Science Foundation (NSF) sponsorship of three.

The DARPA funding is part of its Human Computer Interaction Program. Altogether eleven universities, companies, and government labs have been part of this effort. The NSF funding—under its own Human Computer Interaction Program—has gone to thirty-four universities.[83] Research being undertaken includes work on three-dimensional graphical user interfaces; intelligent, animated, and lifelike computer characters capable of natural face-to-face conversational interaction; and an "intelligent room" embedded with vision, speech understanding, multimedia, and networked interactive computing systems.

The eleven DARPA-sponsored projects include important industry connections. In addition to major cosponsors such as Intel, NTT, and the Information Technology Research Institute, lower-level funding has come from the likes of Acer, America Online, Apple, Discovery Communications, GE, Hewlett-Packard, Hughes Research, NCR, NEC, Nokia, Philips, Sony, and Toyota. DARPA-sponsored students from these ongoing HCI projects have gone on to take positions with these companies as well as with AT&T Research, Bell Labs,

82. Intel Computing Continuum Conference (2000).

83. Program websites: <http://www.darpa.mil/ito/research/uc/index.html>, <http://www.darpa.mil/ito/research/com/index.html>, and <http://www.interact.nsf.gov/cise/descriptions.nsf/Pages/FE08190821C66676852565D9005733CE>.

TABLE 1. Human Interface Panel, March 2000

	Research Group	Major Sponsors[1]
Ronald Cole University of Colorado	Center for spoken Language Research	National Science Foundation Office of Naval Research DARPA Intel
Patrick Hanrahan Stanford University	Computer Graphics Laboratory	Department of Energy Intel
Raj Reddy Carnegie Mellon	School of Computer Science/Speech Group	DARPA
Ben Shneiderman University of Maryland	Human–Computer Interaction Laboratory	National Science Foundation[2] NASA Bureau of the Census European Union DARPA
Victor Zue MIT	Laboratory for Computer Science/Spoken Language Systems Group	DARPA National Science Foundation Information Technology Research Institute NTT

[1] Major sponsors as identified by presenter; listed in order of importance.
[2] Listed in order of projects presented.

Compaq, Dragon Systems, General Magic, IBM Research, Lucent, Microsoft Research, Sarnoff, and Silicon Graphics.

The names of the researchers have changed and the number of funded universities has grown since the 1960s. While the results may not match those of the earlier period, no matter what the results the government influence remains pervasive.

7. Conclusion

> *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 twenty-five years, revolutionized how people interact with computers.*
>
> Stuart Card, Xerox PARC (1996)[84]

Bill Gates is not alone in holding the views quoted at the beginning of this article. His is the mainstream perspective on the development of the PC industry—and indeed on the development of virtually the entire "new economy."

84. Card (1996), p. 162.

Witness Tim Draper, founder and managing partner of Draper Fisher Jurvetson (DFJ). DFJ is "perhaps the top venture firm for Silicon Valley startups."[85] Draper personally provided startup capital for Hotmail (the world's largest email provider), Four11 (the internet white pages directory), and *Upside* (one of the most widely read business technology magazines). In 1997, Draper penned an editorial that articulated much of Silicon Valley's attitude toward the government—an attitude legitimated by the publication in which it appeared, the *Wall Street Journal*. Draper starts by stating that he "earned an MBA from Harvard and an electrical engineering degree from Stanford. I worked at Hewlett-Packard and Alex. Brown before starting a venture capital firm. My favorite periodicals are *Upside* and the *Red Herring*, not the *Washington Post* or the *Weekly Standard*. In my free time I surf the Net; I don't watch Capital Gang or C-SPAN." Writing under the title, "Silicon Valley to Washington—Ignore us, Please," Draper then shares his view of Washington:

> We in the high tech business have reason to feel good … Our industry now accounts for 11 percent of gross domestic product and a quarter of U.S. manufacturing output. We employ more than 4.2 million people, who earn almost double the average salary of manufacturing workers. Our industry is the biggest reason the U.S. has the world's most competitive economy …
>
> We ought to count our blessings that most of our industry is 2,500 miles from Washington and that most bureaucrats either fear, don't care about, or don't understand technology. And we've done just fine without their help … Washington doesn't understand my business, [and] I'd like it to stay that way. The fact is that politicians and government bureaucrats can't help us; they can only get in the way … If the U.S. wants more good jobs, better lives, and a stronger economy, the best thing lobbyists, bureaucrats, and politicians can do is *leave us alone*.[86]

"We've done fine without their help" and "they can only get in the way" are typical of how many "new economy" participants view the development of their own industry. This view permeates coverage in *Fortune* and *Business Week* and the general media. Even the highly regarded six-hour PBS documentary on the history of the PC, *Triumph of the Nerds*, overlooks the government connection.[87]

In contrast, we have observations such as those of Stuart Card quoted at the beginning of this section. Card might be in a position to know. He has been with Xerox PARC for twenty-five years, and currently heads its User Interface Research Group. His comment comes from a fifty-page technical paper he compiled on the historical development of HCI.

Card is not alone. Brad Myers, Senior Research Scientist at Carnegie Mellon's Human Computer Interaction Institute, warns against "the mistaken impression

85. *The Argua,* July 3, 1999.
86. Tim Draper, "Silicon Valley to Washington—Ignore us, Please," *Wall Street Journal*, 4 March 1997. Emphasis in original.
87. *Triumph of the Nerds* (1996). Interestingly, the producer's sequel on the origins of the internet, *Nerds 2.0.1* (1998), starts with a major segment on ARPA's contribution.

that much of the important work in Human–Computer Interaction occurred in industry."[88] Instead, as computer historians Martin Campbell-Kelly and William Aspray have written, "almost all the ideas in the modern computer interface emanated from laboratories funded by ARPA's Information Processing Techniques Office."[89] Even one of Silicon Valley's own—Charles Gescheke, President and cofounder of Adobe Systems—acknowledges that it was ARPA support that "has allowed the current PC industry to flourish."[90] Uncovering this political–economic link provides an important corrective to the popular lore surrounding the origins of the personal computer. This article has sought to "bring the state back in" to the PC realm of apparent market purity.

Government support for the development of the PC should take its place on a list that includes the internet, the computer chip, and the PC's bigger brother, the mainframe.[91] The federal government's role in supporting the development of the internet is now widely acknowledged. The ARPANET of 1969 was followed by the NSFNET of 1985. This support extends to the government's ongoing Next Generation Internet project. The government's support of the chip industry goes back to military R&D funding in the 1940s and procurements into the 1960s by the Air Force and NASA of 100 percent of the industry's production. Government support of the chip industry would continue into the 1980s and 1990s with the Very High Speed Integrated Circuit Program and Sematech consortium.

And, of course, Defense and Energy Department support of the mainframe and supercomputer industry stretches from the ENIAC of 1945, IBM's 1953 Stretch computer, the SAGE computer in 1954, Cray's first supercomputer in 1976, the 1996 Intel teraflop machine, and even IBM's 1997 chess champion Deep Blue. This kind of support continues today with government programs such as the High Performance Computing and Communication Initiative and the Accelerated Strategic Computing Initiative.

The internet, the computer chip, the mainframe, and the PC: together these four innovations define the information technology revolution that has fueled the new economy of twenty-first century. No doubt university and corporate researchers as well as private entrepreneurs have made this revolution possible. But popular mythology, corporate PR, and political ideology aside, much credit also goes to government.

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88. Myers (1998).
89. Campbell-Kelly and Aspray (1996), p. 266.
90. Geschke (1999).
91. Regarding some of these other areas of government support, see Fong (2000). The nature of government support across these various cases differs of course, and this article develops a typology that clarifies some of the differences. The Windows case would fall in this typology's "by-product" category.

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