Popularizing the Internet

In the 1990s the Internet emerged as a public communications medium, and there were countless commentaries on its social impacts and implications. To the novice user, the Internet seemed to be an overnight sensation—a recent addition to the world of popular computing. The reality was different. In addition to the two decades of work that had gone into the development of packet switching networks, it took a series of transformations over the course of the 1980s and the early 1990s to turn the Internet into a popular form of communication.

At the beginning of the 1980s, the Internet included only a relatively small set of networks, most of which had direct links to defense research or operations. Over the course of the 1980s and the 1990s, the Internet would grow enormously in the number of networks, computers, and users it included; it would be transferred from military to civilian control; and its operation would be privatized, making the network much more accessible to the general public. Only then could most people grasp the possibilities for information gathering, social interaction, entertainment, and self-expression offered by the Internet and by an intriguing new application called the World Wide Web.

The question of who was responsible for creating this popularized Internet has no simple answer; because no single agent guided the system's evolution. ARPA was the original creator of the Internet technology, but during the 1980s that agency relinquished control over the Internet itself. A host of new actors assumed responsibility for various aspects of the system, including the National Science Foundation, the Bush and Clinton administrations, various public and private bodies outside the United States, university administrators, Internet service providers, computer vendors, and the system's many users. With the loss of a central guiding vision from ARPA, the system seemed at times to verge on anarchy, as control of the network became fragmented among diverse groups with competing interests and visions. The Internet was also swept up in fast-moving changes in the technology, economics, and politics of computing and communications that made it difficult for anyone to foresee or plan its long-term development.

How did the Internet fare as well as it did under these turbulent conditions? I argue that the combination of an adaptable design and a committed user community accounts for its success. On the technical side, the Internet's modularity made it possible to change parts of the network without disrupting the whole, its robustness allowed it to function under the stress of rapid growth, its scalability helped it expand gracefully (although it did encounter some bottlenecks), and its ability to accommodate diversity allowed it to incorporate new types of networks. The techniques that made the Internet so adaptable—the TCP/IP protocols and the system of gateways—were adopted by network builders around the world, who hoped to join their networks to the Internet or at least achieve the same technical benefits. On the social side, ARPA (and later the NSF) worked hard to expand access to the Internet and to make TCP/IP easily available to potential users. The culture of the Internet also contributed to its widespread appeal. The Internet community's decentralized authority, its inclusive process for developing technical standards, and its tradition of user activism encouraged new groups to participate in expanding and improving the network, and the openness of the system invited users to create new applications (of which the World Wide Web would be the most dramatic example).

In this chapter I describe how the Internet was transformed from a research tool into a popular medium. I follow the system's growth and reorientation toward civilian research during the first half of the 1980s and the subsequent role of the National Science Foundation in further expanding it and, eventually, turning its operation over to the private sector. Along the way I explore some technical, managerial, and political issues raised by the Internet's expansion, privatization, and increasing economic importance. I then consider how the Internet became a global network, examining the role of...
independent networking developments in the United States and elsewhere and concluding with the
emergence of the World Wide Web in the early 1990s.

**Increasing Civilian Participation**

At the start of the 1980s, the Internet—still under military control—consisted of a mixture of operational and research networks, many still experimental. Over the course of the 1980s, the balance shifted away from military involvement and toward academic research. New groups of researchers from outside the community of ARPA contractors began to gain access to the ARPANET, and military users moved to their own, more defense-oriented networks.

The first step in expanding civilian access to the Internet was initiated by the community most intimately involved with the technology: computer scientists. In the late 1970s, only a dozen or so computer science departments were connected to the ARPANET. The schools with ARPA contracts enjoyed access to specialized computers and increased professional communication and collaboration—benefits that their colleagues without access to the ARPANET noticed with envy. This created a demand for network access that had not existed before, as computer scientists at the majority of schools without ARPA contracts—who had no comparable networking facilities—began to feel that they were at a professional disadvantage.

In May of 1979, Lawrence Landweber, chairman of the University of Wisconsin's computer science department, called a meeting of his colleagues at a number of schools to discuss possible solutions to their lack of network access. Beyond their local institutions' resources, university computer scientists had two main sources of funding: ARPA and the National Science Foundation. While ARPA tended to provide larger amounts of money, it supported only a select few research groups, whereas the NSF distributed its grants among a much larger number of schools. Landweber's group believed that the NSF would be receptive to the idea of funding a network that would serve a large number of researchers, and their efforts were encouraged by the head of the NSF's Computer Science Section, Kent Curtis. They submitted a proposal to the NSF for a new network, called CSNET, that would link computer science departments around the country.

This first proposal, which would have used public X.25 networks, was turned down by NSF reviewers on the basis of its technical design. In June of 1980 the group held a second planning meeting. This time Vint Cerf from ARPA attended the meeting, and he suggested some key changes in the CSNET plan. Cerf proposed that CSNET use the Internet protocols, which had not been part of the original design, and he offered to set up connections between CSNET and ARPANET. Cerf's plan promised to benefit both ARPA-funded and non-ARPA-funded researchers by creating a single online community of computer scientists. And for ARPA there was another advantage. In 1980 TCP/IP was still being used by only a few sites, and ARPA managers were eager to get more people involved in using the new protocols. Creating a new network that used TCP/IP would ensure that the ARPA protocols got the attention and support of the computer science community (Landweber 1991).

The new plan for CSNET was further enhanced by an idea presented at the meeting by Dave Farber; a computer scientist at the University of Delaware. Farber described work he and his colleagues were doing on a system that would make it possible to build a low-cost network using dial-up telephone links. This offered a way to expand CSNET membership to schools that could not afford a full-time network connection.

After the meeting, the planning group prepared a second proposal for a composite network that would link sites by combining leased connections from the commercial Telenet network, a set of dial-up telephone connections that was referred to as PhoneNet, and the ARPANET TCP/IP would be used by all the hosts communicating over this new internet. In 1981 the NSF granted $5 million to fund the CSNET project. To build their new network, the computer scientists created the PhoneNet system and set up Internet gateways between the ARPANET, Telenet, and PhoneNet. Computer science departments would connect to one of the three constituent networks, depending on their funding situation: ARPA contractors used the ARPANET, sites that could afford a full-time network connection
subscribed to Telenet, and sites with little funding relied on PhoneNet. CSNET began operation in June of 1982 and was funded by the NSF until 1985, when it became self-supporting through member dues. The system included about 25 ARPANET hosts, 18 hosts using Telenet, and 128 hosts on PhoneNet (Quarterman and Hoskins 1986, p.945).

The network created by the computer scientists broadened access to the Internet considerably. CSNET membership was open to any computer science institution -academic, commercial, nonprofit, or government- that was willing to pay dues. (Commercial use of the network was prohibited.) Putting a host on the ARPANET had required an expensive investment in hardware and software. CSNET's Telenet service was less costly, and the PhoneNet option offered network access that any school could afford. CSNET also expanded international links to the Internet, at least for the limited purpose of exchanging electronic mail. CSNET was permitted to set up email gateways to the research networks that had been built in Germany, France, Japan, Korea, Finland, Sweden, Australia, Israel, and the United Kingdom. Those countries agreed to make sure that their links to the Internet were used only for approved research purposes (Landweber 1991; Quarterman and Hoskins 1986, p.945).

While the Internet was still largely confined to the scientific community, CSNET set a precedent for opening up access beyond ARPA's own contractors. Internet managers Cerf and Kahn, who had come from the academic world themselves, were strongly disposed to expand network access among universities, and under their management the distinction between military and civilian use became something of a fiction. As long as the universities provided their own local infrastructure (Telenet or PhoneNet connections), and as long as the government's network was not exploited for profit, there were few political obstacles to opening up the system.

It became even easier to allow civilian access to the ARPANET in 1983, when the Department of Defense split the ARPANET into the MILNET (for military sites) and ARPANET (for civilian research sites). After the split, the civilian and military networks developed along separate paths. The Department of Defense continued to develop and operate a number of networks, both classified and unclassified, and the MILNET was incorporated into a larger system of military networks known as the Defense Data Network or the Defense Integrated Systems Network.

The purpose of the ARPANET/MILNET split had been to separate the military's operational and research communities so that they could manage their respective networks according to their own needs and priorities; there was no immediate plan to relinquish military control of the ARPANET Still, the network split would make it more feasible to turn the Internet into a public service. Had the Department of Defense continued to use the ARPANET for its daily operations, it seems doubtful that the network would ever have been opened to the public. But the security restrictions that the Defense Communications Agency had imposed on the Internet during its administration were no longer a concern now that the military had its own networks. With university researchers once again the dominant population on the ARPANET, the Internet took on a decidedly more civilian character.

**Growth at the Periphery**

Another way that civilian researchers gained access to the Internet was through local-area networks at their universities. One of the most striking things about the Internet in the 1980s was its meteoric growth. In the fall of 1985 about 2000 computers had access to the Internet; by the end of 1987 there were almost 30,000, and by October of 1989 the number had grown to 159,000 (MERIT 1997). Most of the explosive growth of the Internet during the latter half of the 1980s came not from an expansion of the ARPANET itself but from the growing number of networks that were attached to it.

Where did these new networks come from? The growth of local-area networks was spurred by a computing revolution of the late 1970s and the 1980s: the rise of small, locally controlled computers. The first type of small computer to spread through the research community had been the minicomputer; introduced in the early 1960s, which allowed individual research groups to own and administer their own computers. The 1970s brought the even smaller and more affordable microcomputer -soon dubbed the "personal computer;" since an individual could afford to own one.
Unlike the large machines of the computing world, with their military and corporate roots, personal computers had sprung from the culture of amateur electronics hobbyists. The first personal computer; the Altair 8800, had been introduced in 1975 as a build-it-yourself kit. By 1977 there were a number of "plug-and-play" machines available in the United States, including the Apple II, the Commodore PET, and the Tandy/Radio Shack TRS-80. In 1981 IBM entered the market with its own PC, which quickly became an industry standard. Personal computers were marketed as machines for lay people rather than experts and for use in the home as well as the office or laboratory. Many Americans were eager to own a computer; whether they were fascinated by the technology itself or whether they were hoping to realize the gains in skill and productivity that it promised.

In the 1980s, a new type of single-user minicomputer; the workstation, was adopted by many corporations and academic institutions. Workstations typically featured the Unix operating system and sophisticated graphical displays. As microcomputer technology evolved, the distinctions between personal computers and workstations began to blur and they began to share much of the same underlying hardware.

The growing popularity of single-user computers in universities and businesses stimulated a demand for local-area networks to connect them. When research teams had shared the use of large time sharing computers, they could send email or share data by moving files around within a single computer. Once they were using separate computers, it became harder to share information-unless those computers could be networked together. Xerox PARC researcher Robert Metcalfe addressed that very need in 1975 when he devised the Ethernet system, which provided a simple and inexpensive way to network computers within a local area. Metcalfe later left Xerox to form a company called 3Com to commercialize his invention, and in the early 1980s 3Com introduced commercial Ethernet products that made it easy for people to build their own LANs for Unix workstations and personal computers. Ethernet was eagerly adopted by organizations with large numbers of small computers, and by the mid 1990s there were 5 million Ethernet LANs in operation (Cerf 1993; Metcalfe 1996, p. xix). Other LAN technologies, such as token ring and token bus, were also introduced. Universities and businesses quickly began building LANs, and those that had ARPANET connections began attaching their LANs to the Internet.

Whereas the growth of the ARPANET had been centrally planned, the attachment of LANs to the Internet was a remarkably decentralized phenomenon, depending largely on local decisions at the individual sites. The modularity of the Internet made it relatively simple to attach new networks -even those that used a very different technical design, such as Ethernet. ARPA managers Cerf and Kahn permitted and encouraged contract sites to connect their LANs to the Internet. This would have been a rather extraordinary move for a commercial network; however; ARPA was not in the business of selling Internet service, so its managers had no incentive to restrict access for economic purposes. From their perspective, having a larger user community enhanced the value of the Internet as a research tool with little extra cost to the agency, and the robust and decentralized nature of the system minimized the need for ARPA to exercise central control over its expansion. That few outside the research community knew or cared about the Internet in the early 1980s also helped make it politically feasible for ARPA to let the system expand in an informal way. No one in Congress was arguing over who should or should not be allowed access to the Internet, or at what cost.

In fact, far from restricting access, ARPA took an active part in making it easier for sites to create TCP/IP-based LANs and connect them to the Internet. In order for an ARPANET site's local network to be connected to the Internet, two technical requirements had to be met: the site had to run TCP/IP on the local network, and it had to set up a gateway (also called a router) between its network and the ARPANET. ARPA helped out with both tasks. Dave Clark at MIT, who coordinated the technical development of TCP/IP through most of the 1980s, provided versions of TCP/IP that could run on personal computers (Leiner et al. 1997). ARPA funded a number of vendors to develop TCP/IP products for Ethernet, and it published its own official standard for transmitting IP packets over Ethernet in April of 1984; the companies involved often went on to commercialize these products (Hornig 1984). By 1985 there was a healthy commercial market for products that allowed minicomputers and microcomputers to run TCP/IP over Ethernet. ARPA contractors also developed
and commercialized Internet routers, and by the mid 1980s a market had developed for off-the-shelf routers.

Thus a series of developments that began far from ARPA came to have a significant impact on the Internet. The combined effect of the growth of PCs and LANs, the commercial availability of TCP/IP software and routers, and ARPA's open-door policy was that LANs began joining the Internet in droves (Cerf 1993). In 1982 there had been only 15 networks in the Internet; four years later there were more than 400 (NSF Network Technical Advisory Group 1986, p.3). The addition of LANs to the Internet meant that a new group of local network managers took on responsibility for managing parts of the system. As universities attached their LANs to the Internet, its resources became accessible to academics who were at ARPA-funded institutions but were not necessarily involved in work funded by or related to the military.

What’s in a Name?

Although the Internet could afford to grow in a decentralized and spontaneous way, there were still certain functions for which central coordination seemed to be needed to prevent chaos. One of the most important of these functions was providing a uniform and comprehensive system of host names and addresses that would allow each computer to be uniquely identified. In order for Internet hosts to exchange messages, each host had to be able to obtain the addresses of all the others; there also had to be some way to make sure that no names or addresses were duplicated. This called for some type of system-wide coordination.

In the early 1980s, as the number of hosts and networks on the Internet began to rise, the original naming system showed signs of strain. Each host computer on the Internet has both a name (a set of characters -often a recognizable word- that can be used to refer to the host) and a numerical address (used by the network to identify the host). This dual identity relieves users of having to deal with cumbersome numerical addresses, but the system requires that there be a way to map names onto addresses. To translate names into addresses in the old Internet system, each host kept a table of names and addresses for all the other hosts on the Internet. The host table had to be updated whenever hosts were added, were removed, or changed their point of attachment to the network - events that occurred often. The Network Information Center was responsible for approving new host names and for maintaining and distributing updated host tables; however; it often fell behind on these tasks, and many host administrators began using their own unapproved but up-to-date host tables. When the NIC did distribute updated host tables, the sheer size of the files threatened to swamp the network with traffic as they were sent out to hundreds of hosts. Host administrators complained about the inadequacy of this system, and it was clear to everyone that further growth of the Internet would only exacerbate the problem.

To address this issue, members of the Internet technical community began discussing the idea of dividing the Internet name space into a set of smaller "domains." Host names would take the form "host. domain," and individual users would be identified as "user@host. domain." The Domain Name System, as it came to be called, was largely designed by Paul Mockapetris at the University of Southern California Information Sciences Institute, and was adopted by the Internet in the mid 1980s (Cerf 1993; Leiner et al. 1997). Its goal was to distribute the task of maintaining host information in order to make it more manageable. Instead of having a single organization maintain files of all the host names and addresses, each domain would have at least one "name server;" a special host that maintained a database of all the host names and addresses within that domain. When a host needed to find the address of another host, it would send a query to the name server for the destination host's domain, and the name server would return the address of the destination host.

The Domain Name System eliminated the need to distribute large files containing host tables across the network at frequent intervals. Instead, updated host information would be maintained at the name servers for the various domains. Host computers would no longer have to keep tables listing hundreds of host names and addresses; now they needed to know only the addresses of a small number of domain name servers. Later; the system was adapted to recognize addresses on non-TCP/IP
networks, which made it easier for people whose networks were not part of the Internet to exchange mail with Internet users.Domains could theoretically represent any subset of the Internet, such as an organization, a type of organization, or even a random selection of hosts. In practice, ARRA decided to create six large domains to represent different types of network sites: edu (educational), gov (government), mil (military), com (commercial), org (other organizations), and net (network resources). (Additional domains were subsequently added.) This division by type of host was designed to make it easier to manage the domains separately: the military could control the “mil” domain, an educational consortium could administer the “edu” domain, and so on. Beneath the top-level domains were other; site-specific domains, and these in turn could be further divided to create a nested hierarchy of domains. For instance, within the top-level domain “edu,” each university would have its own domain; a university could then choose to give different departments or other groups their own domains within the university domain (Mills 1981; Krol 1992, pp. 26-27). This decentralized the naming process: the administrator of each domain could assign lower-level domain names without consulting a central authority. Host names had to be unique within a domain, but the same host name could be used in different domains, since the combination of host and domain names would still be unique. If people at several universities wanted to name a machine “frodo” after the character in J. R. R. Tolkien’s Lord of the Rings (a common preference among computer science students), it would be permissible. Thus, there was no need to coordinate naming above the level of the local domain. The Domain Name System provided a way to keep the task of finding addresses manageable, to facilitate email exchange among diverse networks, and to distribute the authority for naming hosts and lower-level domains (Mills 1981; Krol, 1992, p. 27; Cerf 1993).

The National Science Foundation Takes the Lead

ARPA’s activities in funding computer science during the 1960s and the 1970s had been paralleled, on a much smaller scale, by those of the National Science Foundation. In the 1980s, in the wake of its sponsorship of CSNET, the NSF began to build large networks of its own and became involved in the operation of the Internet. The NSF’s pursuit of networking greatly expanded the size and scope of the Internet, opened up access to virtually every interested university, and eventually brought the Internet under civilian control.

The NSF’s Office of Computing Activities had supported computing centers at various universities since the mid 1960s, and NSF managers were sympathetic to the idea of building networks to connect these centers (Aufenkamp and Weiss 1972, pp. 227-228). As early as 1972 the NSF began studying the possibility of developing a national network to pool hardware resources, encourage collaboration beyond institutional boundaries, and share programs and databases (ibid., p.226). The NSF did not attempt to build such an ambitious network in the 1970s, perhaps because of its relatively small budget and perhaps because the potential importance of such a network to researchers was not yet recognized. Instead, it funded some smaller networks that linked clusters of universities on a regional basis.

In the 1980s, the NSF began planning its own nationwide network. The impetus for this was the NSF’s new supercomputer program. In mid 1984 the NSF created an Office of Advanced Scientific Computing, whose mandate was to establish several new supercomputer centers around the United States. To make those publicly funded machines available to a wider community of researchers, the NSF simultaneously began planning for a high-speed network to link the supercomputer centers and provide access to other universities (Quarterman and Hoskins 1986, p.309). The NSF would spend $200 million to operate the NSFNET over the next ten years.

The NSF planned its network as a two-tier system. University computer centers would be linked to regional networks, which would be connected in turn to a central network known as the “backbone” of the NSFNET. The backbone would comprise a set of packet switches connected by high-speed leased lines. Each participating regional network or supercomputing site would have a gateway to one of the backbone switches. The first version of the backbone linked the NSF’s six supercomputer sites;
eventually, the backbone included 16 nodes, each of which served one or more supercomputer centers, national laboratories, or regional networks (Wolff 1991, p. 1). Thus, the NSFNET was conceived from the beginning as an internet, not a single network.

The idea of building regional networks followed from earlier NSF activities. In the period 1968-1973, the NSF’s Office of Computing Activities had funded 30 regional computing centers as a way to help universities make efficient use of scarce computer resources -and also to make sure that elite schools would not be the only ones to benefit from computers (Aspray 1994, p. 69). One offshoot of this program was a number of networking experiments aimed at making access to these regional centers easier. The NSF subsidized regional networks that enabled cooperating institutions to share resources; it also provided startup funding to help academic consortia build their own self-supporting networks. Examples of consortia-run networks included the New England Regional Computing Program (NERComp), which built a network connecting 40 New England universities to seven main computing sites in 1971; the Michigan Educational Research Information Triad (MERIT) network, begun in 1972; and EDUNET, a nation-wide education network built by EDUCOM, a consortium of educational computer centers and networks (Cornew and Morse 1975, p.523; Farber 1972, p.38; Quarterman 1990, p.318; Emery 1976).

With the inauguration of the NSFNET project, the NSF stepped up its support for regional networks. With encouragement from NSF program managers, groups of universities in various parts of the United States organized regional projects and submitted funding proposals to the agency. By early 1988, seven new regional networks were in operation, including BARRNet (in the San Francisco Bay area), MIDNet (in the Midwest), NorthWestNet, NYSERNET (in the New York area), Sesquinet (in Texas), SURAnet (in the Southeast), and WESTNET (in the Rocky Mountain region) (Quarterman 1990). In addition, the NSF sponsored a number of regional networks specifically for supercomputer access and the University Satellite Network (USAN), which linked several universities by satellite to the National Center for Atmospheric Research in Boulder. These new systems and the existing MERIT network were all linked to the NSFNET by 1988 (figure 6.1). Other regional networks continued to be created and linked to the NSFNET backbone.8

Figure 6.1. The NSFNET in 1989. Source: MERIT 1989. The supercomputer networks were JVNCNet at Princeton, NCSAnet at the National Center for Supercomputing Applications at the University of Illinois, PCSnet at the Pittsburgh Supercomputer Center, and SDSNet at the San Diego Supercomputer Center.
The initial version of the NSFNET, designed collaboratively by personnel at the various sites, was only temporary (MERIT 1995). The NSF sought competitive bids from commercial contractors to build a more advanced version of the backbone, and in 1987 it awarded a five-year contract for building and operating an upgraded version to MERIT, with IBM to supply the packet switches and MCI to provide the leased lines. The original network had used the "fuzzball" protocols created by David Mills of the University of Delaware, but the designers of the upgraded network, led by Dennis Jennings of the NSF, decided that it should use TCP/IP. This move reflected an effort by the NSF and ARPA to coordinate their network activities. To pool their resources, the two agencies agreed that while the new NSFNET backbone was being designed and built, the NSFNET would use the ARPANET as its backbone and the NSF would share some of the ARPANET's operating costs (Barry Leiner; email to author; 29 June 1998). This scheme required that the NSF's regional networks run TCP/IP so as to be able to communicate with the ARPANET.

The NSF-ARPA interconnection arrangement opened the Internet to nearly all the universities in the United States, making it a civilian network in all but name. The NSFNET also introduced some new actors to the Internet system, including nonprofit regional network operators and the new supercomputer centers (which provided the network's most impressive resources and created concentrations of computer experts around these resources). The regional networks and the supercomputer centers would play important roles in the privatization and popularization of the Internet.

The End of the ARPANET

As the Internet grew, its backbone network, the ARPANET, was beginning to show its age. By the late 1980s the ARPANET was almost 20 years old—quite a long time in the computer field. The system's IMPs and 56-kilobits-per-second lines no longer had the capacity to serve the escalating number of users of the Internet system, which was estimated in 1987 to have several hundred thousand computers and as many as a million users. In December of 1987, the managers of ARPA's network program, Army Major John Mark Pullen and Air Force Major Brian Boesch, decided that the ARPANET had become obsolete and would have to be retired.

But what would replace the ARPANET as the communications system for ARPA researchers and the backbone of the Internet? At first, the ARPA managers envisioned building a new network (to be called the Defense Research Internet), transferring users to it, and then dismantling the ARPANET. But there was another possibility: to connect the ARPANET sites to the NSF's regional networks, and to have the NSFNET take over as the backbone of the Internet. The NSFNET was being designed with higher-speed lines and faster switches than the ARPANET, so it would be able to handle more traffic. Since the NSF and ARPA were already operating their network services jointly, and since many of their sites overlapped, this option appealed to the ARPA and NSF managers. When the NSFNET backbone was ready, it would simply be a matter of transferring the entire Internet community from the ARPANET to the NSFNET.

The design choices that Cerf and Kahn had made in creating TCP/IP made this backbone swap relatively easy. The Internet's designers had decided to give the host computers, rather than the network itself responsibility for most of the complicated networking functions. Those functions would not be disrupted, therefore, by changes in the backbone networks. Keeping the network's tasks simple had given the Internet system needed flexibility.

During 1988 and 1989, the various ARPA contract sites transferred their host connections from the ARPANET to the NSFNET. On 28 February 1990 the ARPANET was formally decommissioned and the remaining hardware dismantled. The changeover caused little disruption in network service; most ARPANET users were probably not aware that the transition had taken place. But Vint Cerf penned a "Requiem for the ARPANET," which concluded as follows:

It was the first, and being first, was best, but now we lay it down to ever rest.
Now pause with me a moment, shed some tears.  
For auld lang syne, for love, for years and years 
of faithful service, duty done, I weep.  
Lay down thy packet, now, O friend, and sleep.  
(Cerf 1989)

Cerf’s sentiments were echoed by other ARPANET veterans who had witnessed the network’s remarkable 20-year evolution from an uncertain experiment to a system that routinely served hundreds of thousands of users. The end of the ARPANET was not simply a sentimental occasion, however: the passing of the baton from ARPA to the NSF also marked the end of military operation of the Internet.

Privatization

Although the Internet had come under civilian control, it was still run by a government agency and still intended only for nonprofit research and education. The final step toward opening the network to all users and activities would be privatization. The issues that the NSF faced in trying to privatize the Internet were in some ways very characteristic of US attitudes toward the role of the federal government. Americans tend to disapprove of government involvement in providing commercial goods or services, as the heated debates in the 1990s over the establishment of a national health care system or federal subsidies for high-tech research and development illustrate. Therefore, the NSF managers believed that the only politically feasible way to accommodate commercial users on the Internet would be to remove it entirely from government operation.

ARPA managers had tried as early as 1972 to persuade a commercial operator such as AT&T to take over the ARPANET, but they had not been successful; in 1972 it was not evident that the market for data network services was big enough to interest a giant corporation. By the early 1990s, however; the Internet had grown by several orders of magnitude, the advent of personal computing had vastly expanded the potential market for network services, and the once-monolithic telecommunications industry had been opened to smaller carriers who might be more interested in entering the computer networking market. The National Science Foundation would find privatizing the network more feasible than ARPA had, though the task still raised some thorny issues.

At the beginning of the 1990s the NSF had to make difficult decisions about the future of the Internet, some having to do with the network’s users and others with the contractors who operated it. All users of the NSFNET backbone (which was now the Internet backbone too) were required to abide by the NSF’s Acceptable Use Policy, which stated that the backbone was reserved for “open research and education” and which specifically prohibited commercial activities.” The Acceptable Use Policy was a political necessity, since Congress was quick to condemn any use of government-subsidized resources for commercial purposes.12 However; the policy was unpopular with users, and the fact that many sites were involved in both research and commercial activities made it hard to enforce. It was clear to members of the Internet community that the conflict between policy and practice would only get worse as more and more businesses began using computer networks.

At the same time, commercial network service providers were demanding that the NSF give them an opportunity to compete for the business of providing backbone services. MERIT and its partners IBM and MCI were operating the backbone under a contract from the NSF that would expire in 1992. In 1990, this group spun off a nonprofit corporation called Advanced Network Services (ANS) and subcontracted the backbone operations to this new entity (MERIT 1995; Wolff 1991). ANS then set up its own for-profit counterpart, which began offering commercial network services. These developments caused consternation within the Internet community: it was one thing to have a nonprofit consortium such as MERIT running the network, but quite another to have a commercially involved enterprise such as ANS exercise monopoly control over the provision of Internet backbone services.

NSF managers saw privatization as the solution to their worries about users and contractors. If they could shift the operation of the Internet from the NSF to the commercial sector and end government subsidies of its infrastructure, the issue of acceptable use would disappear And with the private sector
supplying Internet services, network companies could compete for customers in the marketplace, rather than competing for NSF contracts. In 1990, NSF manager Stephen Wolff began discussing the idea of privatizing the Internet with interested members of the Internet community, holding workshops and soliciting comments from network experts, educational groups, and representatives of other government agencies. Wolff found a “broad consensus” within the Internet community that the NSF should arrange for several competing companies to provide backbone services (Wolff 1991, pp. 1-2). The question was how to plan the transition from government to private operation in a way that was both equitable and technologically feasible.

One development that aided the NSF’s efforts was the rise of commercial network services. In the short time since the NSFNET had been created, the American networking environment had changed dramatically. In 1987, the operator of the ARPANET -Bolt, Beranek and Newman- had been the only company with experience running a large-scale TCP/IP network. But the subsequent growth of the NSFNET spawned a number of commercial network service providers, and by 1991 there was a thriving and competitive market for high-speed nationwide computer networking services. The possibility existed, therefore, of having several companies share responsibility for the Internet backbone.

Where had all these commercial networks come from in so short a time? Some of them were direct spinoffs of the NSF’s own regional networks. Just as members of the ARPANET project had spun off commercial services such as Telenet, so the creators of regional networks had created commercial Internet ventures. The first of these entrepreneurs was William L. Schrader; who had led the creation of NYSERNet in 1986. Like all the NSF regional networks, NYSERNet used a physical infrastructure of communications links and packet switching computers to provide a particular service: TCP/IP-based connections between the region’s host computers and the rest of the Internet. What Schrader and the other network operators who followed him did was separate -conceptually and legally- the operation of the infrastructure from the provision of the service.

By the late 1980s, the use of computers and local networks in business had grown to the point where a potentially lucrative market existed for networking services. In 1989 Schrader founded Performance Systems International (later known as PSINet) and began offering TCP/IP network services to business customers (PSINet 1997). To provide these services, PSINet bought out NYSERNet’s infrastructure. NYSERNet became a broker of network service rather than a provider; buying service from PSINet and selling it to NSF-sponsored users. Since the network infrastructure was no longer directly paid for by the US government, PSINet could also sell its services to business customers for additional profits. PSINet proved to be a successful business venture, and other spinoffs of regional networks quickly followed along the same lines.

The new network providers served both NSF research and education sites and commercial customers. However; since commercial traffic was still forbidden on the NSFNET, only the NSF-sponsored sites could send traffic through the NSFNET backbone; traffic from commercial customers had to be routed through the network service provider’s own backbone. This encouraged most of the new companies to expand their backbone operations from their original regional areas to the entire continental United States. MCI, AT&T, Sprint, and other telecommunications carriers also began to offer commercial Internet services (Cerf 1993). By the mid 1990s, a whole parallel structure of commercial TCP/IP networks had evolved.

One handicap for these service providers was that the only connection between their various networks was the Internet backbone, which was off limits to traffic from commercial customers. To increase the scope of service for commercial users, three of the new service providers -PSINet, CERFNet, and Alternet- joined together in July of 1991 to form a nonprofit organization called the Commercial Internet Exchange (CIX). The CIX set up a gateway to link the three networks, the operation of which was financed by a membership fee, and the members agreed to accept traffic from any other member network free of charge. This free-exchange policy spared CIX members the considerable trouble and expense of setting up the technology to support an accounting system for network traffic. In any case, the network providers would have found it difficult to pass on access charges to their customers.
Unlike the telephone system, computer network customers were not charged on the basis of how far their packets traveled; indeed, they often did not even know the physical locations of the computers to which they sent packets, and they were even less likely to know which commercial network a computer was on. Under these circumstances, trying to impose charges for sending packets between networks would have caused great technical difficulties and, in all likelihood, would have outraged customers.

The CIX arrangement, which allowed the customers of any member network to reach users on all the other networks, greatly increased the value of the service each network provided. Other commercial networks soon joined the CIX to gain these benefits for themselves, and there were eventually dozens of CIX members worldwide. Since the commercial networks were also providing the Internet's regional infrastructure, the only physical difference between the CIX and the Internet was that they had different backbones. With the commercial networks imposing no restrictions on the type of traffic they would carry; the CIX became, in effect, a commercial version of the Internet, offering the same set of connections to a different clientele.

With this commercial infrastructure evolving rapidly, the NSF could plan to replace its own Internet backbone with a commercially based operation. In November of 1991 the NSF issued a new Project Development Plan, which was implemented in 1994. Under the new plan, Internet service would be taken over by competitive Internet Service Providers (ISPs), each of which would operate its own backbone, and the old NSFNET backbone would be dismantled. Customers would connect their computers or LANs to one of the commercial backbones. There would be a set of gateways, called "exchanges," at which two or more ISPs would connect their systems according to bilateral agreements, thus allowing traffic to be sent from one network to another.

The government, meanwhile, would create a new segment of the Internet, called the "very-high-speed Backbone Network Service" (vBNS), which would be restricted to specialized scientific research. The NSF gave contracts to four Internet Service Providers to operate a set of gateways between their networks and the vBNS, so as to ensure easy access for the research system's users. Aside from the research-oriented vBNS, however; the commercial version of the Internet had become the only version. On 30 April 1995, MERIT formally terminated the old NSFNET backbone, ending US government ownership of the Internet's infrastructure (MERIT 1995).

With privatization, the Internet was opened up to a much larger segment of the American public, and using it for purely commercial, social, or recreational activities became acceptable. Commercial online services could now offer Internet connections, and the computer industry rushed into the Internet market with an array of new software products and services. Corporations that had built their own long-distance data networks because of the prohibition on commercial use of the Internet could put their computers on the Internet and phase out their expensive private networks (Krol 1992, p. 17). As a flood of new users joined the network, the Internet suddenly became the focus of new social issues involving personal privacy, intellectual property, censorship, and indecency. At the same time, network users created a whole new set of applications (for example, the role-playing games known as "multi-user dungeons") to fulfill their desires for entertainment, social interaction, and self-expression. The Internet became a topic of public discussion, and ordinary people began to debate the advantages and pitfalls of "going online."

Convergence with Other Networks

In parallel with the development of the Internet in the 1970s and the 1980s, a host of other networks with diverse technical approaches, management philosophies, and purposes had been created. In the days when Internet access was restricted, these networks provided alternative options for network service. With the privatization of the Internet, the independent networks contributed a large population of experienced network users to the Internet community, as well as some new applications that would appeal to a public in search of social interaction or amusement on the Internet.
The ARPANET had publicized the benefits of computer networking in the early 1970s. Later in that decade, a number of individuals and organizations began to experiment with providing these benefits to computer users who were excluded from the ARPA community and could not afford commercial network services. These grassroots networks, designed to be inexpensive, were usually run as cooperatives, with a minimum of central coordination. They were user-driven efforts; some received modest funding from the computer industry but others had no outside support at all.

Some resourceful computer users improvised their own electronic message services, using operating system software that had been provided for other tasks. For example, when AT&T distributed the 1978 version of its Unix time sharing system, it included a program called UUCP (Unix-to-Unix copy) that allowed users to copy files from one computer to another. Almost immediately, computer users at universities, where Unix was widespread, took advantage of this program to create an informal email network. The UUCP network was a simple affair: instead of having its own networking infrastructure, it relied on periodic dial-up telephone connections between hosts to exchange mail files. The only central management was a map of participating hosts that was used to route mail through the system, and this was maintained by volunteers.

The UUCP software was also used by two students at Duke University, Tom Truscott and Steve Bellovin, as the basis of a system for the distribution of electronic newsletters. In 1979 they set up a news exchange system between Duke and the University of North Carolina, using dial-up connections. Word of this system spread to people at other universities, who were invited to copy the software and join the news exchange. Soon an informal network that came to be known as USENET was created. Described by its founders as “a poor man's ARPANET,” USENET provided inexpensive network communications for many schools that had no other access to a national network (Quarterman 1990, p. 243). USENET was used to distribute online forums called “newsgroups” that featured a variety of different topics. Any user at a USENET site could submit messages to a newsgroup, which would then be available to all other readers of the newsgroup; this enabled users to participate in an ongoing discussion. Users could create newsgroups on any topic they wanted to discuss. Most of the early newsgroups focused on practical matters of using and operating computers, but soon social and recreational groups sprang up to discuss sex, science fiction, cooking, and other subjects. Computer users flocked to USENET because it offered new possibilities for social interaction, bringing together “communities of interest” whose members might be geographically dispersed and allowing people to participate anonymously if they chose. Users could select which newsgroups to read, and a number of programmers developed and distributed software that made it more convenient to select newsgroups and read messages. Designed and managed by its users and having no obligations to the government, USENET was even more decentralized and freewheeling than the Internet.

Another improvised service made use of the IBM RJE (remote job entry) protocol, a standard feature of the operating systems of IBM machines that allowed the user of one computer to submit programming jobs to another. Since the RJE software was designed to transfer program files from one computer to another, it only took a little modification to use it to exchange other types of files, such as mail. In 1981, Ira Fuchs at the City University of New York and Greydon Freeman at Yale University obtained funding from IBM to create an experimental connection between their two schools using RJE. This became the first step in building a network for IBM users, which was named BITNET (The “BIT” acronym stands for “Because It’s There,” referring to the system builders' adaptation of an existing protocol.) Like the UUCP network, BITNET was used primarily for electronic mail, although it also allowed a pair of users to “chat” in real time over a dial-up connection. IBM provided funding to support software development and administrative work at CUNY, which served as a hub for the exchange of mail among the various BITNET sites. This funding ended in 1986, and the network became self-supporting through modest user fees. Like the ARPANET, BITNET and USENET were examples of how network users could take tools that had been designed for computation and adapt them for personal communication.

When personal computers became common, in the early 1980s, computer ownership became possible for a new groups of users who often did not have access to institution-based networks. Some users set up their computers to serve as "bulletin boards" by adding a modem and software that
allowed others to dial in to the machine and post messages, to which other users could respond. One popular system for bulletin boards was named Fido. In 1983, Tom Jennings, the operator of a Fido bulletin board, created FidoNet, which used dial-up connections to allow the exchange of messages between Fido machines. By 1990, when about 2500 computers had joined FidoNet, its applications ranged from a forum for handicapped people to a directory of databases created by the United Nations (Quarterman 1990, pp.257-258).

Cooperative networks were organized in an informal way; joining a network required only that one arrange to periodically call another site on the network to exchange mail or news files. The expenses entailed in joining such networks were limited to the cost of one’s telephone calls and sometimes a small membership fee; this made them attractive to individuals and organizations with limited computing budgets, including political and social activists. Soon USENET, BITNET, and FidoNet were serving thousands of host computers in the Americas, in Europe, in Australia, in Asia, and in Africa (Quarterman 1990, pp. 230-239). BITNET spawned branches in Canada (called NetNorth) and Europe (called EARN), all of which were connected to form a unified email system. Networks combining USENET and UUCP services were set up in Europe (EUnet) and in Japan (JUNET). USENET, BITNET, and FidoNet also set up gateways to allow the exchange of mail with one another. These low-cost networks helped spread the benefits of network technology -previously the domain of the wealthier nations, organizations, and individuals- to less privileged groups.

By the mid 1980s, the grassroots systems were being imitated by commercial email services on existing telephone or computer network systems: MCI Mail, AT&T Mail, Telenet's Telemail, DEC's EasyLink, and others. In addition, IBM, DEC, and other large computer companies had built their own wide-area networks that linked the companies employees around the world. These networks used the manufacturer's own proprietary protocols and were not open to outside users, so they did not represent an option for the general public, but they increased the overall population of network users who might later choose to join the Internet.

Another popular form of computer communication was the use of conferencing systems, also known as "online services." A conferencing system was not a network per se but rather a single computer site into which users could dial to post messages, download files, exchange email, or participate in real-time online conversations. The early 1980s saw the introduction of commercial online systems, such as CompuServe, America Online, and Prodigy, which catered to the personal computer user. Subscribers would access these services by means of a modem and software supplied by the service provider. In their original form, these online services did not offer access to the Internet (which was still restricted); they simply connected users to the provider's own computer system, which offered features such as free software, access to online shopping or other services, and the opportunity to "chat" with other subscribers. This non-networked form of online service, now largely forgotten, was instrumental in introducing large numbers of users to the practice of accessing information and interacting with other people via a distant computer.

Some conferencing systems were set up to serve particular communities or regions. In 1985, for instance, the WELL (Whole Earth 'Lectronic Link) was set up by Stewart Brand (of Whole Earth Catalog fame) and Larry Brilliant (head of a California software company) as an alternative to the commercial online systems (Figallo 1995, p. 51) The WELL, intended to foster a sense of local community for its members in the San Francisco area, became known as a gathering place for advocates of counterculture ideas and free speech. It was run on a modest commercial basis, charging minimal fees to recover its expenses and relying heavily on volunteer work by its users. Many other "alternative" conferencing systems -such as PeaceNet, created in 1985 by peace activists- were nonprofit services. Most were open to all interested participants for the cost of the telephone connection plus a nominal fee to cover operating expenses.

By the late 1980s, therefore, several million computer users could exchange mail and news over the various grassroots and commercial networks. Though these systems were not parts of the Internet, they established links to it fairly soon ARPA permitted mail from other systems to be sent to Internet users, and in the early 1980s it sponsored the development of software that would allow hosts to act
as “mail relays,” receiving mail from one network and sending it into another after performing any necessary reformatting. Sites that had connections to both USENET and the Internet began sending USENET news files between the two networks, and news soon became a standard feature for Internet users-so much so that in 1986 members of the Internet community developed a protocol called NNTP for the specific purpose of transmitting news files over TCP/IP-based networks.

The cooperative networks had been designed to use software that was specific to a particular type of computer or operating system, since their creators had used existing software tools. Eventually people adapted the software for use on computers of other types; however the various networks were still incompatible. In addition, because the networks used different naming and addressing schemes, users who wanted to send messages from one network to another were forced to use awkward address formats, such as:

```
ucp:host1!psuvax1!host.bitnet!username
```

or

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username%host.domain.junetdomain@csnet-relay.csnet.
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As more people joined these networks and had trouble communicating with users of other networks, the network coordinators began to consider adopting more general-purpose protocol standards. Outside the United States, network operators most often chose to adopt the OSI protocols, which were an international standard rather than an American one (Quarterman 1990, pp. 232, 252). In the United States, the cooperative networks chose to adopt the Internet protocols, both because they wanted better access to the large Internet community and because they considered TCP/IP to be the best available option for providing a common language between networks. In the late 1980s the US portion of BITNET gave up the RJE system in favor of TCP/IP and a version of UUCP was developed to run over TCP/IP. In 1986 the BITNET and UUCP organizations also agreed to adopt the Internet’s Domain Name System; FidoNet followed in 1988 (ibid., pp. 111, 256).

Even before privatization, then, the commercial and nonprofit networks had interacted extensively with the Internet. Once the Internet had been privatized, many users of cooperative networks began to switch to Internet Service Providers. This represented the convergence of two strands of network development: the users of grassroots networks adopted the Internet infrastructure, while the Internet community adopted newsgroups and other applications that had been popularized by the cooperative networks. Commercial online services also joined the Internet. In many cases they became little more than Internet service providers, abandoning their original role as content providers; however; chat rooms and other services they had popularized entered the mainstream Internet culture. These independently developed applications and the many users who had been drawn to networking through the grassroots and commercial services helped fuel the Internet’s growth and popularity.

**Management Issues**

Privatizing the Internet backbone had been relatively easy, but the transition to commercial operation left open the question of who would provide ongoing technical planning and administration for the system. Each member network, from the smallest LAN to the largest Internet Service Provider, was responsible for its own operations. However; protocol development, administration of Internet names and addresses, and other tasks that affected the entire system still required some central coordination—a function that the National Science Foundation could no longer provide.

The NSF adopted a range of methods for delegating various aspects of the management of the system, many of them similar to approaches used in other newly privatized industries. Some coordination functions were vested in nonprofit, non-government bodies. The educational consortium MERIT, for instance, continued to act as the central authority on Internet routing information even after it ceased to operate the NSFNET backbone. In other cases, control over administrative functions was split among competing commercial entities, on the theory that market competition would encourage
innovation and prevent any one interest group from gaining too much power. For instance, in the late 1990s, as Internet domain names such as “microsoft.com” began to be seen as valuable symbols of organizational identity and even intellectual property, the question of who should assign these names became hotly contested. Some people believed that name registration should remain under the central control of the InterNIC, a government-designated nonprofit body. Others, claiming that the InterNIC was slow, unresponsive, and careless in its business practices and arguing that competition would provide better service to people applying for domain names, proposed turning the job over to a number of commercial name registrars. This proved a difficult issue to resolve: since there might be several groups trying to register a particular name, there were many potential losers in the naming process, and they were likely to criticize whatever system was in place.

The technical side of managing the privatized Internet was little changed from the ARPANET days, in part because there was a good deal of continuity in the core group of computer experts who made the technical decisions. The ARPANET Network Working Group had set the style for technical development with its informal, participatory process and its use of Requests For Comments to propose and comment on protocol standards. This approach was similar to the committee-run, consensus-based style of many standards organizations, though without the usual restrictions on membership. The NWG disbanded in the early 1970s as the ARPANET went into full operation, but its methods were perpetuated by the series of technical oversight groups that succeeded it.

During the 1970s, the Internet Program -run by NWG alumni Vinton Cerf and Robert Kahn- took on responsibility for ongoing protocol development. Cerf and Kahn set up an advisory group of network experts called the Internet Configuration Control Board. One of this board's jobs was to encourage a wide spectrum of potentially interested parties within the network community to contribute to and debate the merits of the system’s evolving protocols. If consensus on a proposed protocol seemed to emerge, the ICCB would often arrange for a few Internet sites to create implementations of the protocol to see how it worked under actual use; if the protocol was tested successfully, the ICCB would declare it an official Internet: standard.

Barry Leiner; as ARPA’s network program manager from 1983 to 1985, reorganized this management structure in an effort to broaden in decisions about network’s design. He replaced the rather small circle of the ICCB with a more inclusive body called the Internet Activities Board, which was chaired by Dave Clark of MIT for many years. The leadership of the IAB drew heavily on the research community that had built the ARPANET, with members from the Department of Defense, from MIT, from Bolt, Beranek and Newman, from the University of Southern California's Information Sciences Institute, and from the Corporation for National Research Initiatives (a networking think tank formed by Cerf and Kahn). However, membership in each of these groups was open to anyone, anywhere in the world, who had the time, interest, and technical knowledge to participate.

The Internet Activities Board became a forum for discussing all aspects of Internet policy; and its meetings became very popular in the networking community. By 1989, the number of people participating in the IAB had grown into the hundreds, and its leaders decided to divide its activities between an Internet Engineering Task Force (which would lead protocol development and address other immediate technical concerns) and an Internet Research Task Force (which would focus on long-range technical planning) (Postel and Reynolds 1984, pp. 1-2; Kahn 1990). Working groups within these task forces coordinated their activities through email, and the task forces held meetings several times a year Standards for the Internet were set by consensus, after discussion among all interested parties and after proposed protocols had been tested in practice, and they continued to be published electronically in the form of Requests for Comments (Quarterman 1990, pp. 184-186).

When the National Science Foundation began its NSFNET project, it set up its own Network Technical Advisory Group, chaired by David Farber at the University of Delaware. After the managers of the NSF and ARPA decided to merge their networks, the NSF folded its technical group into ARPA's Internet Engineering Task Force. In the ensuing years, the IETF took on members from the Department of Energy and NASA too, and it became the single arbiter of internetworking standards for the federal government.
With privatization, and with the spread of the Internet around the world, it became politically necessary to move the system’s technical administration out of the US government. In January of 1992, the Internet Society, a nonprofit organization, was assigned formal oversight of the IAB and the IETF. In addition, the Internet Society took on the task of disseminating information about the Internet to the general public. The Internet Society, the IAB, and the IETF included members from all sectors of the Internet community, and international participation in these three groups increased over the course of the 1990s.

Throughout these changes, the Internet's administrative and technical structures remained remarkably decentralized. No one authority controlled the operation of the entire Internet. Drawing on the examples provided by the ARPANET culture and by contemporary experiments with privatization, the Internet community evolved several principles for reducing chaos and conflicts of interest in a decentralized and heterogeneous system. These included having multiple competing service providers wherever feasible; designing the system to maximize the number of operational decisions that could be made at the local level; and, in cases such as protocol standards where it is necessary to have a single decision-making group, having that group be inclusive and democratic.

Yet it has continued to be difficult for the Internet community to work out management policies that satisfy every interest group. The administrative structures of the Internet have been in a state of flux ever since privatization, as different solutions have been tried, and the ultimate source of the authority of the Internet Society, the IAB and the IETF remains uncertain. With unusual candor, a 1997 FCC policy paper noted the following:

The legal authority of any of these bodies is unclear. Most of the underlying architecture of the Internet was developed under the auspices, directly or indirectly, of the United States government. The government has not how ever; defined whether it retains authority over Internet management functions, or whether these responsibilities have been delegated to the private sector. The degree to which any existing body can lay claim to representing "the Internet community" is also unclear (Werhach 1997)

As the Internet becomes more of an international resource, the continued authority of the United States in administrative matters will, no doubt, be challenged more and more.

**The Global Picture**

Today, few if any countries are without at least one connection to the Internet. How did this worldwide expansion occur? Though the Internet originated in the United States, it did not simply spread from the United States to the rest of the world. Rather; its global reach resulted from the convergence of many streams of network development. Starting in the 1970s, many other nations built large data networks, which were shaped by their local cultures and which often served as agents and symbols of economic development and national sovereignty. The question was not whether these countries would adopt an American technology; it was whether and how they would connect their existing national or private networks to the Internet.

Since the early 1970s the ARPANET and the Internet had included sites outside the United States; University College London had an ARPANET connection for research purposes, and ARPYs Satellite Network linked the United States with a seismic monitoring center in Norway. The defense portion of the Internet also connected many overseas military bases. But the Internet's ownership by the US government was an obstacle to connecting it with civilian networks in other nations. ARPA and NSF managers feared that such connections would be perceived by the American public as giving away a taxpayer-subsidized resource to foreigners, and citizens of other countries might regard the encroachment of US networks as a form of imperialism. Overseas, grassroots user-supported networks with lower political profiles, such as BITNET and UUCP, spread faster than the Internet.
Before privatization, therefore, it was difficult to expand the Internet abroad by adding host sites to the US-run networks; connecting the Internet to networks in other countries was much more promising. By the mid 1970s, state-run networks were being built in a number of countries, including Canada, Germany, Norway, Sweden, Australia, New Zealand, and Japan (Carpenter et al. 1987). In addition to these national networks, there were several efforts to build multinational networks across Europe in support of the creation of a European Union. These included the European Informatics Network (established in 1971) and its successor, Euronet. Some of the networks were, like the ARPANET, designed for research and education; others provided commercial network services.

France Telecom, with its Minitel system (introduced in 1982), was the first phone company to offer a network service that provided content as well as communications. Since few people in France owned or had access to computers at that time, the phone company encouraged widespread use of Minitel by giving its customers inexpensive special-purpose terminals they could use to access the system. Minitel allowed millions of ordinary people to access online telephone directories and other commercial and recreational services (including online pornography, a popular attraction that received much public comment and that the US-government-run Internet could not have openly supported).

One of the world's leading sites for computer networking was CERN, the European laboratory for particle physics. Owing to the peculiar needs of its users, CERN had a long history of networking (Carpenter et al. 1987). Experimentalists in high-energy physics must travel to accelerator sites such as CERN. While there, they generate huge amounts of data. In the early 1980s, to make it easier to transfer such data around its laboratory in Geneva, CERN installed local-area networks. Physicists also need to communicate with and transfer data to their home institutions. To accommodate this need, CERN joined various wide-area networks, including EARN (the European branch of BITNET), the Swiss public data network, and HEPNET (a US-based network for high-energy physics).

Networks outside the United States had few links to the Internet while it was under military control. But when the National Science Foundation set up its civilian NSFNET, foreign networks were able to establish connections to it, and thus to gain access to the rest of the Internet. Canada and France had connected their networks to the NSFNET by mid 1988. They were followed by Denmark, Finland, Iceland, Norway, and Sweden later in 1988; by Australia, Germany, Israel, Italy, Japan, Mexico, the Netherlands, New Zealand, Puerto Rico, and the United Kingdom in 1989; and by Argentina, Austria, Belgium, Brazil, Chile, Greece, India, Ireland, South Korea, Spain, and Switzerland in 1990 (MERIT 1995). By January of 1990 there were 250 non-US networks attached to the NSFNET, more than 20 percent of the total number of networks. By April of 1995, when the NSF ceased operating it, the Internet included 22,000 foreign networks -more than 40 percent of the total number (ibid., file history.netcount). The system had truly become international in scope, though its membership remained highly biased toward wealthy developed countries.

The other industrialized nations approached networking rather differently than the United States. In the United States, the federal government operated military and research networks, but public network services were provided on a commercial basis. In other countries, the public networks were government-run monopolies, so network decisions involved overtly political maneuvers as well as business considerations. In many countries, people viewed the expansion of US networks such as the Internet with alarm, seeing it as further evidence of US economic dominance in the computing industry. Thus, while many people inside and outside the United States favored expanding the Internet around the world, politically charged differences between network systems presented a number of barriers.

One technical obstacle was incompatibilities among network systems. Initially, many networks outside the United States had used proprietary network systems or protocols designed by their creators. Most state-run networks eventually adopted the official CCITT or ISO protocols, which they regarded as the only legitimate standards; few if any used TCP/IP.

In the mid 1980s, however; many private network builders outside the United States began adopting TCP/IP, perhaps because they had become impatient with the slow introduction of ISO standards. In
November of 1989, a group of TCP/IP network operators in Europe formed RIPE (Réseaux IP Européens meaning European IP Networks). Similar in concept to the CIX (and perhaps providing a model for that system), RIPE connected its member networks to form a pan-European Internet, each network agreeing to accept traffic from the other members without charge. RIPE also provided a forum for members to meet, discuss common issues, and work on technical improvements. By 1996, RIPE had as members more than 400 organizations, serving an estimated 4 million host computers (RIPE 1997).

While the Internet protocols were gaining popularity outside the United States, many network operators wanted to reduce the United States' dominance over the Internet. One contentious issue was the structure of the Domain Name System. Since the ultimate authority to assign host names rests with the administrators of the top-level domains, other countries wanted to have their own top-level domains. Responding to these concerns, ISO promoted a domain name system in which each country would have its own top-level domain, indicated by a two-letter code such as “fr” for France or “us” for the United States. Within these top-level domains, national governments could assign lower-level domains as they saw fit. The new system provided autonomy and symbolic equality to all nations. However, the old Internet domain names based on type of organization (educational, military, etc.) were not abolished. In the United States, most organizations continued to use them, rather than adopting the new “us” domain (Krol 1992, p.28).

Since the Internet originated in the United States, its “native language” is English -a fact that has caused some resentment among other linguistic groups. The dominance of English on the Internet has led to political disputes over what is often seen as American cultural or linguistic imperialism. In the mid 1990s, for example, the French government, which had put in place a number of measures to maintain French-language content in the media, required every Web site based in France to provide a French version of its text. Internet users whose native languages do not use the Roman alphabet have struggled to get support for extended character sets (Shapard 1995).

Finally, the expansion of the Internet has been limited by global disparities in the telecommunications infrastructure that underlies network access. In 1991, for instance, the number of telephone lines per 100 inhabitants in industrialized nations ranged from 20 (in Portugal) to 67 (in Sweden); in much of South America, Africa, and the Middle East, there were fewer than 10 lines per 100 inhabitants, and China, Pakistan, India, Indonesia, and Tanzania -countries with a huge percentage of the world's population- had fewer than one line per 100 people (Kellerman 1993, p.132). Clearly, the unequal distribution of wealth among nations will continue to shape the Internet's worldwide role. The Internet, as a medium of instantaneous communication, might overcome geographic distance, but it cannot simply erase political or social differences.

The World Wide Web

In the 1980s the Internet's infrastructure grew impressively, but network applications lagged behind: email and file transfer were still the most common activities, and there were few user-friendly applications to attract novices. One factor that discouraged wider use of the Internet was its drab text-only interface, which contrasted sharply with the attractive graphical interfaces found on many personal computers. CompuServe, America Online, and Prodigy took advantage of the personal computer's graphic capabilities to provide attractive, user-friendly interfaces, thus setting a precedent for providing online information that incorporated images. Some software developers were also trying to create more graphics-oriented interfaces for Unix work-stations (notably the X Windows system, developed at MIT in the mid 1980s), but many users of time sharing machines were still confined to text-based network interfaces.

Another drawback to using the Internet was the difficulty of locating and retrieving online information. File-transfer programs were available, but the user had to know the names of the desired file and its host computer; and there was no automated way to get this information. In former times it had been the ARPA/NET Network Information Center's role to provide information on network resources, and even then the information it had provided had often been inadequate. The privatized Internet had no
central authority to create a directory of resources, and in any case the size of the Internet would have made the task of maintaining such a directory impossible.

In the early 1990s, new services made it easier to locate documents on the Internet. One such service was the gopher system, developed at the University of Minnesota. The gopher software allowed information providers to organize their information in a hierarchy of related topics; users of the system could select topics from menus, rather than having to know and type in the names of computers and files. Another widely used system was the Wide-Area Information Server; developed by the Thinking Machines Corporation. Instead of using a menu system, WAIS allowed users to search for documents whose text contained specified words; the titles of the documents would be displayed, and the user could retrieve the documents (Schatz and Hardin 1994, pp. 895-896). Services such as gopher and WAIS took a step in the direction of organizing information by content rather than location. There were still many obstacles to finding information on the Internet, however. There was no way to link information found in different documents, and the various protocols that had evolved for exchanging information were not compatible; no one program could handle formats as diverse as ftp, mail, gopher; and WAIS.

All these issues were addressed by a new Internet application that became known as the World Wide Web. The Web would fundamentally change the Internet, not by expanding its infrastructure or underlying protocols, but by providing an application that would lure millions of new users. The Web also changed people's perception of the Internet: Instead of being seen a research tool or even a conduit for messages between people, the network took on new roles as an entertainment medium, a shop window, and a vehicle for presenting one's persona to the world.

Building the Web

The Web did not spring from the ARPA research community; it was the work of a new set of actors, including computer scientists at CERN, the staff of an NSF supercomputer center; and a new branch of the software industry that would devote itself to providing Web servers, browsers, and content.

The first incarnation of the Web was created in 1990 by Tim Berners-Lee, Robert Cailliau, and others at CERN. Berners-Lee appreciated the value of networking; however; he saw a severe limitation in the fact that, though personal computers were becoming increasingly image oriented, most uses of the Internet were still limited to text. He envisioned a system that would help scientists collaborate by making it easy to create and share multimedia data (Berners-Lee et al. 1994, p.82; Comerford 1995, p. 71). CERN had adopted TCP/IP in the early 1980s in order to provide a common protocol for its various systems, so Berners-Lee designed the new service to run over the Internet protocols.

The computing tradition on which Berners-Lee drew was far removed from the military roots of the ARPANET and the Internet: the hacker counterculture of the 1960s and the 1970s. In 1974, Ted Nelson, a vocal champion of this counterculture, had written a manifesto, *Computer Lib*, in which he had urged ordinary people to learn to use computers rather than leaving them in the hands of the "computer priesthood." More to the point, Nelson had proposed a system of organizing information that he called "hypertext." Hypertext would make it possible to link pieces of information, rather than having to present the information in a linear way.

Berners-Lee planned to create a hypertext system that would link files located on computers around the world, forming a "world wide web" of information. To the idea of hypertext he added the use of multimedia: his system included not only text-based information but also images, and later versions would add audio and video. (See Hayes 1994, p. 416; Schatz and Hardin 1994.) The Web's use of hypertext and multimedia drastically changed the look and feel of using the Internet.

In Berners-Lee's vision, the Web would create "a pool of human knowledge" that would be easy to access (Berners-Lee et al. 1994, p.76). Before achieving this goal, however; Berners-Lee and his collaborators had to address a number of technical challenges. First, they had to create a shared format for hypertext documents, which they called hypertext markup language (HTML). To allow the
Web to handle different data formats, the designers of HTML specified a process of "format negotiation" between computers to ensure that the machines agreed on which formats to use when exchanging information. "Our experience," Berners-Lee (1993a) observed, "is that any attempt to enforce a particular representation ... leads to immediatewan... Format negotiation allows the web to distance itself from the technical and political battles of the data formats." Like the ARPANET's designers before them, the Web team chose to create a system that could accommodate diverse computer technologies.

The layered structure of the Internet meant that Berners-Lee could build his new application on top of the communications services provided by TCP/IP His group designed the hypertext transfer protocol (HTTP) to guide the exchange of information between Web browsers and Web servers. To enable browsers and servers to locate information on the Web, there also had to be some uniform way to identify the information a user wanted to access. To address this need, they created the uniform resource locator (URL) -a standard address format that specifies both the type of application protocol being used and the address of the computer that has the desired data. An important feature of the URL was that it could refer to a variety of protocols, not just HTTP This would make it possible to use the Web to access older Internet services, such as FTP, gopher; WAIS, and Usenet news. The accommodation of all Internet services -present and future- within a single interface would be an important factor in making the Web system versatile and user friendly (Berners-Lee et al. 1994, p. 76; Berners-Lee 1993b; Schatz and Hardin 1994, pp. 896-897).

In December of 1990 the first version of the Web software began operating within CERN. Berners-Lee's system was an instant hit with CERN users. It took more than an inspired invention, however; to create an application that would bring the Internet mass popularity. It also required the right environment: widespread access to the Internet (made possible by privatization) and the technical means for users to run the Web software (provided by the personal computer).

Personal computers had brought computing to masses of ordinary Americans in the 1980s, and a decade later they laid the foundation For the popular embrace of the Web. The popularization of the Internet could have occurred without it the personal computer France's widely used Minitel system, for instance, relied on inexpensive home terminals for its user interface. But Minitel (lid not allow users to create their own content -a distinctive feature of the World Wide Web. The Web depended on significant computer power at the user's end of the connection. In addition, the time and energy that individuals had invested in learning to use their personal computers would make it easier for them to acquire the skills needed to access the Web. Thanks to the spread of graphical user interfaces via the Macintosh and Windows operating systems, instructions such as "point and click" seemed obvious rather than perplexing to novice Web users. For non-expert users in particular; the Internet-based Web represented the convergence of personal computing and networking.

**Participation Explodes**

CERN began distributing its Web software over the Internet in the summer of 1991, and in 1992 several other high-energy physics sites set up Web servers (Berners-Lee et al. 1994, p.76; Berners-Lee 1995; Cailliau 1995). Among these sites was the National Center for Super-computing Applications at the University of Illinois, one of the original NSF supercomputer centers. The NCSA had been affected by an unexpected development in computing technology: the decline of the supercomputer. These large machines had seemed state-of-the-art in the early 1980s; by 1990, however; they had lost their appeal for many scientists, since microprocessor-based workstations could provide comparable computer power in a more convenient and much less expensive form. The NCSA found itself with personnel and resources but a dwindling sense of purpose. Marc Andreessen, then a member of the NCSA's computing staff, later commented: "Because it was a Federal undertaking, the Supercomputing program had a life of its own.... NCSA was really trying to figure out what it was going to do and what its role would be." (Andreessen 1995) The center's staff, which had been involved in designing the original NSFNET, decided to increase its emphasis on networking. Network services represented a growing market, and Andreessen and others saw great potential in the Web, which at that time was being used only by a small group of researchers.
In 1993 an NCSA team led by Andreessen began developing an improved Web browser called Mosaic. Mosaic was the first system to include color images as part of the Web page, and these images could, like text words, be used as links (Schatz and Hardin 1994, p.897). More important, Mosaic was available to a much larger group of users than the CERN web browser had been. Mosaic was designed to run on most workstations and personal computers, and it was distributed by the NCSA over the Internet free of charge.

When the NCSA officially released Mosaic to the public, in November of 1993, more than 40,000 copies were downloaded in the first month; by the spring of 1994 a million or more copies were estimated to be in use (Schatz and Hardin 1994, pp. 897 and 900). Once Mosaic was available, the system spread at a phenomenal rate. In April of 1993 there had been 62 Web servers; by May of 1994 there were 1248 (Berners-Lee et al. 1994, p. 80). In 1994 Andreessen and his team left the NCSA to work on a commercial version of Mosaic called Netscape. Netscape simplified the browser's user interface, increased its speed, and added security measures to support financial transactions (Smith 1995, pp. 198.200; Andreessen 1995). The many new features made Netscape browsers (which were also distributed free of charge) a more popular choice for users than the older Mosaic.

Once the Web became popular; other companies began offering commercial browsers, and new businesses sprang up offering services that made it easier to locate information on the Web. The original system had had no way to search the Web; users could only type in a URL or follow links from page to page. Hypertext links continued to provide one important way to find information on related topics, but new programs called "search engines" made it possible to search for topics, organizations, or people on the Web. This went far toward solving the long-standing problem of identifying resources on the Internet, and it gave users more control over the way information on the Web would be presented to them.

The Web completed the Internet's transformation from a research tool to a popular medium by providing an application attractive enough to draw the masses of potential Internet users into active participation. It solidified the Internet's traditions of decentralization, open architecture, and active user participation, putting in place a radically decentralized system of information sharing. On the Web, links between sites were made laterally instead of hierarchically, and each individual could be a producer as well as a consumer of information.

The appearance of personal-computer-based Web browsers coincided with the privatization of the Internet, providing an attractive application for the many users who suddenly had access to the network. Whereas the ARPANET's early users had been beset by difficulties in their attempts to use remote computers, laypersons encountering the Web for the first time found it relatively easy to master. The fact that users could themselves become publishers of Web-based information meant that the supply of Web pages increased along with the demand, further accelerating the growth of the system (Schatz and Hardin 1994, p. 901). The Web's exciting multimedia format and the seemingly endless stream of new features offered by entrepreneurial companies put the Web at the center of public attention in the late 1990s, by which time "the Internet" and "the Web" had become synonymous to many people.

The Legacy of a Protean Technology

If there is a constant in the history of the Internet, it is surprise. Again and again, events not foreseen by the system's creators have rapidly and radically changed how the network has been used and perceived. This protean nature -the ability to take on unexpected and unintended roles- has been largely responsible for the Internet's endurance and popularity, and it explains the network's best-known legacies: the introduction of packet switching and other new techniques and the establishment of a unique tradition of decentralized, user-directed development. Some historians have even seen the Internet as a fitting technological symbol of the "postmodern" culture of the late twentieth century, in which unified authorities give way to multiple stakeholders with complex and contradictory agendas.
If the Internet is a reflection of our times, it may be all the more valuable to know how this unusual system came to be and what has held it together.

This book has explored, in various ways, the protean character of the Internet. The story of the invention of packet switching illustrates how the same basic technique could be adapted to different circumstances, with very different results. The success of packet switching did not depend on the ability of Paul Baran, Donald Davies, or Lawrence Roberts to accurately foresee the future of networking; indeed, all three made many assumptions that turned out to be incorrect. Rather, it was Roberts's ability and decision to build a flexible, general-purpose system that allowed the ARPANET to become a large-scale, long-lived, and highly visible example of the “success” of packet switching.

In the late 1960s the field of computer networking was still in its infancy; there was little theory or experience to provide guidance, and computer and communications technologies were in the midst of rapid change. In building the ARPANET, Roberts and the other system designers managed this uncertainty by incorporating it as an element of the system. Rather than try to rationalize and neatly plan each aspect of the system, the ARPANET's builders designed it to accommodate complexity, uncertainty, error; and change. This was done both through technical choices (such as layering) and by making human beings, with their inherent adaptability, an integral part of the system.

The ARPANET's creators were able to answer the question of how to build a large computer network. They had a harder time demonstrating why people should use one. Users played a crucial part in making the ARPANET more than an elaborate experiment in packet switching. Applications created by users became parts of the infrastructure, thus eroding the boundary between user and producer. By adopting electronic mail rather than remote computing as their favored application, users created a system that met their own needs and provided a compelling argument for the value of networking.

The Internet program of the 1970s took the values of flexibility and accommodation of diversity even further. The Internet's TCP/IP protocols, gateways, and uniform address scheme were all designed to create a coherent system while making minimal demands on the participating networks. The hard work that so many ARPA contractors put into implementing TCP/IP in the early 1980s created a standard technology that could be used relatively effortlessly by those who came after The Internet's builders were able to adapt to challenges from outside, too. Faced with competing international standards that promoted different networking paradigms, Internet supporters worked to incorporate rival standards such as X.25 within their own system and to change the international standards to more closely resemble the Internet model.

In the 1990s, the Internet proved adaptable enough to make the transition to private commercial operation and to survive the resulting fragmentation of authority. The Internet's decentralized architecture made it possible to divide operational control among a number of competing providers, while its open and informal structures for technical management were able (at least in the near term) to survive new commercial and political pressures. The astonishing success of the World Wide Web showed that the Internet remained a fertile ground for network Innovations. The Web drew on new computing technologies (particularly the personal computer and its graphical user interface) and its promoters thrived in the new commercial environment for Internet services. The Web also continued the tradition of decentralized participation in the creation of the system, encouraging individual users to add new content and tools.

As to the future, the only certainty is that the Internet will encounter new technical and social challenges. If the Internet is to continue as an innovative means of collaboration, discovery, and social interaction, it will need to draw on its legacy of adaptability and participatory design.

Notes

1. That most schools chose PhoneNet even though it offered only minimal service suggest that cost was indeed a factor in determining access.
2. See chapter 4 above.
3. Geoff Goodfellow, manager of an ARPANET host system, was able to keep his own host table more up to date than the NIC's. Whereas the NIC had to go through formal procedures to add hosts to its table, Goodfellow simply checked for the presence of new hosts on the network. According to Goodfellow, other host administrators heard that his machine had the most current information on ARPANET hosts, and a large percentage of sites began using his host table in favor of the NIC's (Goodfellow 1997).
4. The domain idea itself had been discussed in the networking community since the late 1970's, and earlier RFCs had proposed possible ways to implement it in the Internet.
5. This description is somewhat oversimplified; in most implementations, the name server would cache frequently requested addresses for the sake of efficiency.
6. This was done by putting the name of the non-TCP/IP network in place of a top-level domain – e.g., “host.binet.” When asked for the address of such a name, the name server would instead return the address of a mail gateway that provide an interface between the Internet and the specified network. The mail gateway would translate the Internet-style address into the address format for the other network.
7. This has also had the effect that lost names convey some information about the site. Conversely, a person who already knows something about an organization can often guess it domain name (e.g. microsoft.com or stanford.edu) –something that is not possible with zip codes or area codes. By choosing meaningful rather than arbitrary designations for domains, the Internet's designers increased usability.
8. The information on NSF regional networks is from pp. 301-338 of Quarterman 1990.
9. See Wolff 1991. The granting of contracts to IBM and MCI was somewhat controversial within the Internet community; Wolff notes that there was “widespread skepticism” about this award, since none of the companies involved had any TCP/IP experience.
10. By 1988 the Internet was estimated to include more than 400 networks, up to 500,000 hosts, and perhaps a million users around the world (Quarterman 1990, p.278).
12. This was a long-standing issue. Years earlier, the RCA Service Company (1972, p. A-83) had noted that political and legal obstacles prevented the ARPANET from being connected to other research networks, such as Michigan’s MERIT network or the IBM-sponsored TSS Network: “Connection of the MERIT system would be looked upon by Congress as providing subsidies to a state resource. The legal ramifications of TSS connection to the network present nearly insurmountable obstacles.”
13. Another factor that favored competition was that the NSF wanted to take advantage of recent technical advances in data communications, such as frame relay and asynchronous transfer mode switching, and they felt that having several backbone providers would encourage the use of a greater variety of new techniques.
14. PSINet's corporate web page gives an interesting glimpse of how the US business community viewed the rather anarchic structure of the Internet --which has been much celebrated by academic users-- with skepticism: “Few in the mainstream corporate world in 1989 knew much about the Internet, and fewer still viewed it as a potential part of their own IT solutions. After all, the roots of the Internet were in the war room and the classroom, not in the boardroom. Worse, no one owned the Internet. No one controlled or managed it. No one was responsible for its performance. Why would any organization… entrust the delivery of their information to such a technology?” (PSINet 1997) To some extent this is a projection of present conditions on the past, since in 1989 the NSF still “owned” and managed the internet (or, at least, its backbone).
15. The NSF actually split network operations into two categories: supplying the backbone infrastructure and overseeing the routing system. The latter task involved maintaining a database of domain name servers that was used by routers throughout the Internet to locate hosts. The NSF decided that the routing authority, which was both technically demanding and critical to the stability system, should remain within a single organization, whereas the provision of backbone services could be divided among several bidders. MERIT eventually received a five-year award to continue its role as Routing Authority (Wolff 1991, p. 4).
16. In a conversation with the author in December of 1997, Robert Morris pointed out that NSF managers probably looked to the telephone industry for inspiration on how to design a system with
multiple competing service providers. The US telephone system had been drastically reshaped in the early 1980s by the breakup of the AT&T monopoly. In the new deregulated system, AT&T and other long-distance carriers were supposed to connect on an equal basis with the local telephone networks, now run by several Bell Operating Companies. The telephone network became, in essence, an "internet" of local and long-distance telephone networks, with completing long-distance "backbones." This was exactly the structure that the NSF was trying to create, and it would have provided an obvious model for the redesign of the Internet—especially since MCI, Sprint, and other phone companies were involved in providing Internet services.


18. By 1982, mail relays had been set up between ARPANET and the commercial Telemail service, and between ARPANET and the British system NIMAIL (Postel, Sunshine, and Cohen 1982, p. 978).

19. Source of examples: Quarterman 1990, pp. 257, 233. In the first example, the user is sending a message from FidoNet to BITNET; in the second, from BITNET to JUNET.

20. The chairman of the IAB held the title "Internet Architect."

21. According to Barry Leiner (email to author, 29 June 1998), the country-code system had actually been envisioned by the original designers of DNS, but the impetus to adopt it as the standard way of designating domains seems to have come from outside the United States.

22. HTML was based on an existing ISO standard called the Standard 8879 (1986); HTML is specified in RFC 1866 (1995).

23. The Internet can thus be seen as an example of a “postmodern” technological system—i.e., one in which the unified operating authority is replaced by a decentralized, contradictory, and even chaotic form of control. See Hughes 1998 for a discussion of postmodern technological systems.