Transforming the Computer from a Calculating Machine Into a Global Telecommunication Network

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In 1945, Alan Turing envisioned the computer as a general processor rather than an arithmetical machine (see Hodges, 2001). Because the computer is a multi-purpose machine, its history can be written in a number of different ways. For example, Martin Campbell-Kelly and William Aspray (1996) wrote about the history of the computer as an information machine. Paul Ceruzzi (1998) wrote about the history of computing from human computers to machines. Others (Abbate, 1999; Bardini, 2000; Freiberger & Swaine, 2000) have written about the development of the personal computer and the evolution of the Internet. In contrast to this earlier research, the historical question examined in this paper is how the computer was transformed from a calculating machine into a global telecommunication network.

However, this is a very broad question. As a result, it is first being explored by looking at the types of communication problems that engineers and computer scientists were exploring when they invented technologies that furthered the development of computing and the Internet. Before describing a series of communication-related discoveries, the term communication will be defined. In this paper the term communication relates to two types of human communication issues: using technology to directly communicate between people, or point-to-point communication, and being able to communicate with technology or human-computer interaction.

Point-to-point communication developed with the telegraph, which enabled people to communicate across distances. As telegraph and later telephone services grew, a shift in telephone network strategies occurred with the development of "switched" networks (see

Williams 1991). As more users connected to telephone networking systems the need for connections exponentially increased. By connecting users through a central "switch," lines can be switched open or closed with one another. For example, early switchboards were established where infamous female telephone operators would literally plug in different lines. These telephone ladies facilitated communication from point A to point B by connecting lines through a central switching unit.

Claude Shannon, who invented information theory, further refined the logic of telephone switching (See Sloane & Wyner, 1993). In a practical sense, Shannon defined the process of electronic communication, which engineers could first apply to the telephone system and later to radio and computer networks. In the social sciences, Shannon's new theory became a seminal model for the newly emerging discipline of communication studies. While engineers were concerned with how to deliver bits of information more efficiently, communication theorists started examining the process of human communication and the meaning of messages that were distributed through a communication system.

Communication occurs within a system that could be electrical, chemical, mechanical, biological or economic. Viewing human society as a system, Norbert Wiener (1948/1961) incorporated information theory into his concept of cybernetics. "Cybernetics is the science of maintaining order in a system, whether that system is natural or artificial" (Campbell, 1982, pp. 22-23). Cybernetics explores the communication between humans and machines through the use of feedback and control. All things in the world have a tendency to become disorderly and they must be corrected to maintain a regular behavior. Feedback can be applied to machine control to test the actual, rather than anticipated, performance of a device. It provides information about how a message is received. Applied to human communication systems, the idea of feedback can be used to describe how human communicators adjust their messages to each other during the conversational process.

In the war effort, Wiener applied the concept of cybernetics and feedback to the building of weapons systems. An original goal of Wiener's research was to build weapons systems in which human and machine components could function together seamlessly. He worked on the need for mechanisms that could accurately predict an aircraft's future position and reduce the effect of human error when controlling artillery units. Humans and machines were joined together into a unified cybernetic system in which the components of the system could communicate with each other. Thus, the communication problem Wiener studied was one between humans and machines to perform a specific task through the use of feedback. Cybernetics and Information theory used mathematical principles to describe a wide range of concepts in language, data analysis, computation, and control that were applied to military systems.

Building on the concepts of cybernetics and feedback, the American military began to integrate human and technological systems on a much larger scale through the development of command, control, communications, and intelligence systems (C^3I). During the Cold War Period, American military forces integrated their human and technological components through C^3I. Defense Department funded computer projects, such as the SAGE air defense system and the NORAD early warning system, led to the development of high-speed memory and magnetic core units along with more advanced computer displays (see Edwards, 1996).

Concern over Soviet development of nuclear technologies spurred on the development of digital, rather than analog, computing technologies. Eventually, digital computer development triumphed over analog machines as general computers replaced special purpose computers (see

Tympas, 1996). Around the same time, Paul Baran became interested in the idea of survivable communications, or how to build a network that would survive a nuclear attack. His solution was a store-and-forward switching system that later became packet-switching (see Abbate, 1999). Independently, Donald Davies of the National Physical Laboratory in England also developed a packet-switching scheme. In contrast to survivability, Davies focused on modernization and economic growth in Great Britain. Davies proposed a national message switching network that was geared to the needs of real-time computing. Baran conceived the idea of packet-switching; Davis independently invented it and applied packet-switching to data communication. Later, Larry Roberts used it in the development of the ARPAnet, which evolved into the Internet.

According to Campbell-Kelly (1988), packet-switching involved the fusing of telegraph store-and-forward message switching networks, and computer timesharing. "Timesharing refers to a computer operating system that slices up a computer's processing time and offers it to numerous users rather than dedicating use of the machine to a single user for a long period of time" (Flamm, 1987). It creates the illusion of simultaneous access to computers and makes real-time interaction feasible.

During the 1960s, real-time or simultaneous computer interaction was a goal of several computer projects, including Sketchpad, and the Augmentation System. In 1960, J.C.R. Licklider authored a paper titled "Man-machine Symbiosis," which described how people should be able to interact with computers. A colleague of Wiener's, Licklider was involved with time sharing systems. He wanted to apply cybernetic principles to computers. In his view, people should be able to interact in real-time with computers. For instance, the Sketchpad project demonstrated the idea of real-time computer-aided drawing and graphics.

In 1962, Ivan Sutherland, Licklider and Shannon's PhD student, finished his dissertation called Sketchpad. Sketched was a sophisticated drawing program that was developed on the TX-2, the first computer built using transistors rather than vacuum tubes. Bell Labs' engineers John Bardeen, Walter Brattain, and William Shockley had invented the transistor, which replaced vacuum tubes as a switching element. Telephone systems of the late 1960s did not use computerized switches; instead message switching systems utilized expensive computers.

According to Janet Abbate (1999) "The fact that packet switching relied on an innovative computer product helps to explain why that technique was consistently explored by computer scientists but not by [telephone] communications experts, even though it drew on aspects of both fields" (p. 40). Moreover, Paul Ceruzzi (1989) has argued that electronics technology and computer science have coevolved. And eventually, digital technology triumphed over analog because, unlike analog computers, digital computers can be used as a universal machine.

As digital computers were developed and packet-switching emerged as a method for computer networking, computers also became easier to operate. According to Alan Kay (1993), many of the good ideas for the future development of computer technology were pioneered in the 1960s. These included Sketchpad for computer graphics; Engelbart's Augmentation System that demonstrated teleconferencing, hypertext, and document management; and Licklider and Taylor's idea of using computers for person-to-person communication networks.

The year 1968 was an important year in the history of computing and communication. In 1968, Engelbart demonstrated collaborative computing at the December Fall Joint ACM/IEEE-CS Joint Computer Conference. The presentation used modems and video projectors to show the Augmentation System being used at the Stanford Research Institute. For this system, Engelbart invented the mouse as a control device and he showed how people could communicate with a computer and each other through a computer network. He pioneered the use of teleconferencing, hypertext, and the sharing of electronic documents (see Barnes, 1997).

The same year, Licklider and Taylor published “The Computer as a Communication Device,” which described using the computer as a means to communicate. They predicted that people would be able to communicate more effectively through a machine rather than face-to-face. The paper emphasized the jointly constructive and interactive nature of person-to-person communication. It also discussed mental models, online communities, and the future affordability of computer technology.

By 1964, a manufacturing base was in place to produce microchips and computers were becoming smaller. The chip was co-invented by Jack Kilby and Robert Noyce around 1959. Ten years later, Noyce and Gordon Moore started Intel to manufacture computer chips. In 1964, Moore observed that integrated circuits were increasing four fold every three years, which meant that chips were getting smaller. “By the year 2000, a chip with the capacity of those 1971 models would sell for a nickel or less” (Reid, 1985/2001). This prediction about the future of chips became known as Moore’s Law. At first, chips were used in calculators. But in 1970, Ted Hoff developed the microprocessor chip for use in calculators. Later, Nolan Bushnell started using the chips for video games, which led to the personal computer revolution.

But prior to the invention of the personal computer, Alan Kay realized the implications of Moore’s Law and he estimated how long it would take before small computers would become available. The estimate was sometime in the late 1970s or early 1980s. At this point, Kay’s concept about computers changed as he envisioned millions of personal machines and users instead of thousands of institutional mainframes. Personal machines would need to be designed as extensional systems in which end-users could tailor and direct the construction of their tools. Around 1969, Kay made a cardboard mock-up of a personal computer called the Dynabook.

In 1971, Kay (1990) accepted a position at Xerox Palo Alto Research Center (PARC) to build an “interim dynabook.” The PARC researchers were busy designing the office of the future. In the process, they built minicomputers, developed Ethernet networking, invented the postscript printer, and experimented with the idea of personal computing. In addition to encouraging PARC researchers to develop small computers, Kay and his team created graphical user interfaces and the Smalltalk programming language.

Making computers easy to use was a central component of the PARC contributions to the formation of a global communications network. Similar to Licklider and Taylor, Kay also viewed the computer as a communications medium. Inspired by the writings of Marshall McLuhan and the LOGO project of Seymour Papert, Kay imagined how children would read and write with a computer. A significant contribution to using the computer as a communication device was the application of learning theory to graphical interface design. Kay’s approach to interface design was primarily based on the educational theories of Jerome Bruner. In his book *Toward a Theory of Instruction,* Bruner started to examine the cognitive processing used by children for activities such as problem solving, conceptualizing, thinking, and perceptual recognition.

Kay adapted Bruner’s ideas to interface design by creating a model called “Doing with Images Makes Symbols.” Kay began to utilize the three different levels of representation in the computer’s interface design. The mouse would be used as a form of enactive representation to actively navigate and manipulate text and icons displayed on a computer screen. Icons and windows were incorporated into the design as a level of iconic representation. The Smalltalk programming language was invented for the symbolic level of representation. For further support of the graphical interface, PARC researchers developed the digital mouse, personal computing, advanced screen displays, windows-style interaction, and applied the desktop metaphor to interface design.

However, a significant PARC contribution to computer-based communication was the easy-to-use graphical interface and the technologies associated with this type of interaction. In 1979, Steve Jobs from Apple Computer, who had previously introduced personal computers into the consumer marketplace, toured the PARC technologies. Jobs immediately realized the importance of the graphical user interface and how it could make computers easier to use. He returned to Apple and applied the graphical design concept to the Lisa and Macintosh computers under development. Steven Levy (1994) contends that the introduction of the Macintosh computer in 1984 brought computing to average people. People no longer had to remember arcane commands to operate their machines, instead they could just point and click on icons.

Public interest in computers, combined with the release of the Macintosh, put computers in the hands of average people. The Macintosh applied Xerox PARC's interface style to an appliance-sized personal computer. Microsoft soon followed Apple by introducing its graphical interface called Windows. Graphical interfaces demonstrated how people could more intuitively interact with machines. But, it was IBM and Xerox PARC that realized computers needed to be networked together. A big difference between the PARC vision of personal computing and Apple's view of personal computers was the networking capabilities. PARC's machines were all networked together and they pioneered the development of Ethernet, which later became a networking standard. Similarly, IBM, coming out of a history of mainframe computer development, included networking with all of their personal computers.

As smaller UNIX-based minicomputers and personal computers were placed in the hands of numerous researchers, students, and individuals, networks began to emerge.   For example, USENET was established to share information between students in computer programs using the UNIX operating system and America Online started as a bulletin board system for people who used Apple computers. As social and professional interest grew for bulletin boards, computer networks and the sharing of electronic documents, these different networking systems built gateways to each other and the Internet emerged. In the 1980s, these various computer networks remained largely in the hands of academics, hobbyists, and computer researchers.   As a personal reflection, in 1989 the Internet connection in my apartment cost $1200 per month while the local bulletin board service and membership in AppleLink were free. These three networks did not talk to each other, but five years later everything would become connected together. Moreover, people were starting to use the Internet to access information placed on the World Wide Web.

In the beginning of the Web, Tim Berners-Lee designed a hypertext database that could be used across different computer platforms. The goal of this system was to enable researchers to share electronic documents across any kind of computer platform and software program.   To achieve this goal, Internet users formatted their documents into the text-based Hypertext Mark-Up Language (HTML). In March 1991, Tim Berners-Lee released the World Wide Web software to a limited number of researchers, but it quickly spread throughout the research community. The following August, the Web software was made available on the Internet.

As the Internet evolved into a global network, the idea of ease of use was further enhanced with the graphical Web browser. Marc Andreessen, a student working at the National Center for Supercomputing Applications (NCSA), designed a Mac-like interface for the World Wide Web. Initially, Andreessen was developing the software as a scientific visualization tool, however, he soon realized that the program could be used by a much larger group of people. Andreessen and Eric Bina wrote the first graphical Web browser called Mosaic. Andreessen soon left academic life to start his own company called Netscape. The success of Netscape gained the attention of Microsoft and Microsoft soon developed its own Internet browser called Internet Explorer. Web browsers help to make the Internet accessible to average people. Both the ease of use and the availability of a global networking system fostered the transformation of the computer into a major communication device.

Currently, the transformation carries on as cellular telephones, wireless networks, and portable computers merge into each other. Moore’s Law continues to predict the future as integrated chips go on to become smaller and they are embedded into all kinds of consumer devices. Many of these devices are designed to connect people to each other, such as picture phones and car navigational systems. Underlying this technological change is a basic need for people to communicate with other people, whether it is face-to-face or through a medium of communication.

Point-to-point communication, through digital telephone networks combined with the development of graphical interface systems that easily facilitate the use of computers, has made global computer networks accessible to millions of people. As chip technology decreases in size and cost, wireless networks are gradually replacing wire-based networks in many geographic regions. Global telecommunication continues to increase and become available to more people located in even the most remote areas of the world, including the Amazon regions of South America. Engineering achievements, such as integrated chips, packet-switching, and the design of graphical interfaces, have contributed to advances in telecommunications and they have enabled these technological achievements to be embraced on a global level though the use of the Internet.

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