Chapter 4

IT Infrastructure: Hardware and Software

LEARNING TRACK 3: TECHNOLOGY DRIVERS OF IT INFRASTRUCTURE EVOLUTION

Technology Drivers of Infrastructure Evolution

The changes in IT infrastructure we have just described have resulted from developments in computer processing, memory chips, storage devices, telecommunications and networking hardware and software, and software design that have exponentially increased computing power while exponentially reducing costs. Let's look at the most important developments.

MOORE'S LAW AND MICROPROCESSING POWER

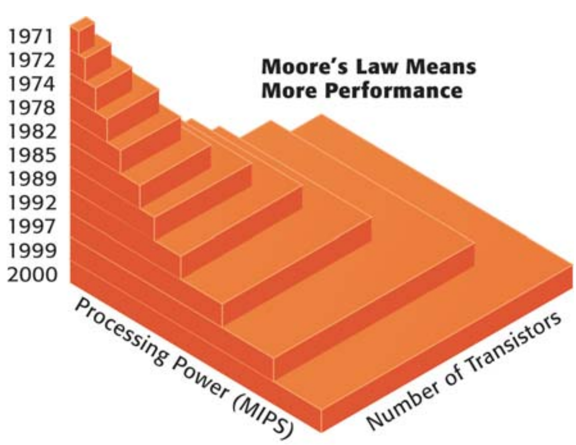
In 1965, Gordon Moore, the director of Fairchild Semiconductor's Research and Development Laboratories, an early manufacturer of integrated circuits, wrote in Electronics magazine that since the first microprocessor chip was introduced in 1959, the number of components on a chip with the smallest manufacturer costs per component (generally transistors) had doubled each year. This assertion became the foundation of Moore's Law. Moore later reduced the rate of growth to a doubling every two years (Tuomi, 2002).

This law would later be interpreted in multiple ways. There are at least three variations of Moore's Law, none of which Moore ever stated: (1) the power of microprocessors doubles every 18 months (Tuomi, 2002); (2) computing power doubles every 18 months; and (3) the price of computing falls by half every 18 months.

Figure 4-3 illustrates the relationship between number of transistors on a microprocessor and millions of instructions per second (MIPS), a common measure of processor power. Figure 4-4 shows the exponential decline in the cost of transistors and rise in computing power.

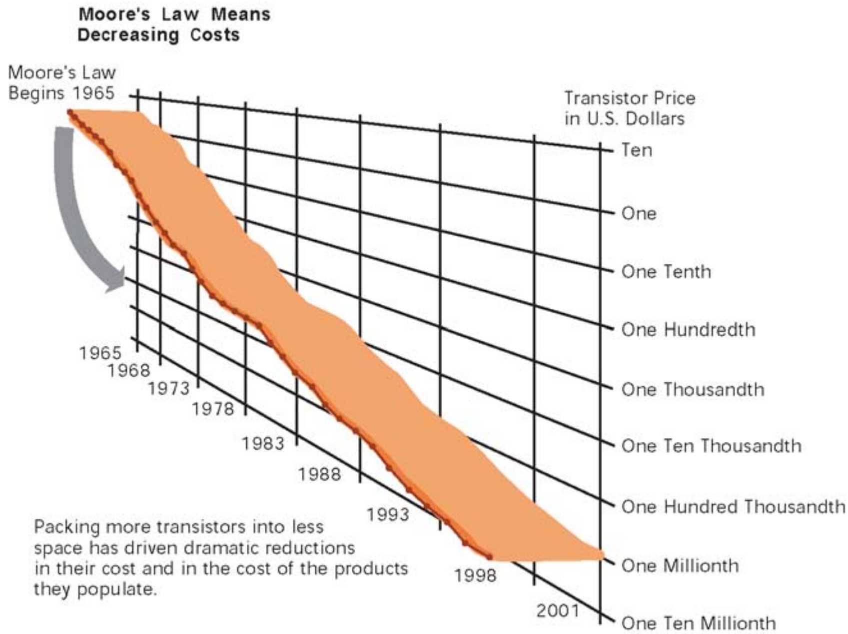
There is reason to believe the exponential growth in the number of transistors and the power of processors coupled with an exponential decline in computing costs will con-

FIGURE 4-3 Moore's Law and microprocessor performance.



Packing more transistors into a tiny microprocessor has exponentially increased processing power.

FIGURE 4-4 Falling cost of chips.



Packing more transistors into less space has driven down transistor cost dramatically as well as the cost of the products in which they are used.

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tinue into the future. Chip manufacturers continue to miniaturize components. Intel has recently changed its manufacturing process from 0.13-micron component size (a micron is a millionth of a meter), introduced in 2002, to a newer 90-nanometer process in 2004 (a nanometer is a billionth of a meter). With a size of about 50 nanometers, today's transistors should no longer be compared to the size of a human hair but rather to the size of a virus, the smallest form of organic life.

By using nanotechnology, Intel believes it can shrink the size of transistors down to the width of several atoms. Nanotechnology uses individual atoms and molecules to create computer chips and other devices that are thousands of times smaller than current technologies permit. IBM and other research labs have created transistors from nanotubes and other electrical devices (IBM, 2004) and have developed a manufacturing process that could produce nanotube processors economically (Figure 4-5). Other new technologies include strained silicon, 300-millimeter production wafers (which decrease the costs of production), and denser interconnections among components.

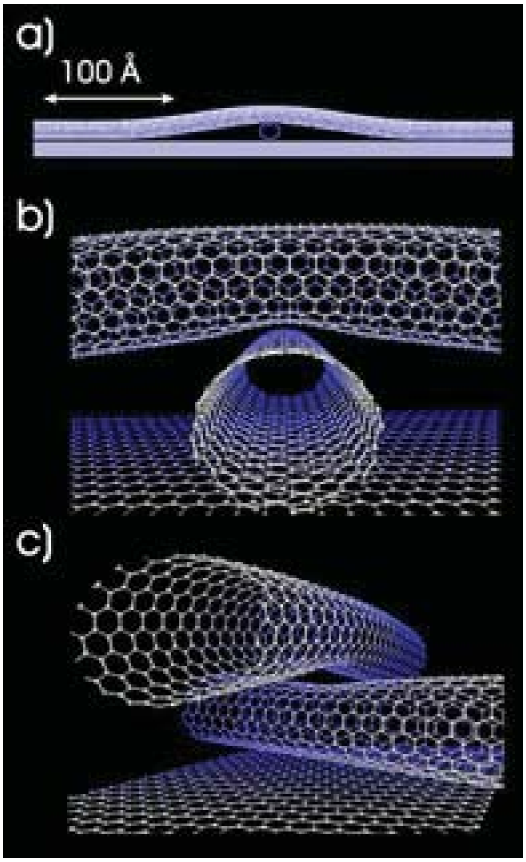
Whereas the first Pentium microprocessors operated at 75 megahertz, today's Pentiums are available with 3-gigahertz speeds. However, increasing processor speeds at the same exponential rate as in the past may no longer be possible. As processor speeds increase, heat is generated that cannot be dissipated with air fans.

Another brake on future increases in microprocessor speed is more market-oriented: Most consumers may not need vast increases in microprocessor speed but instead are more interested in low power consumption for longer battery life and low weight to increase laptop and handheld computer portability. For this reason, Intel and other firms are designing the next generation of chips to be less power hungry and lower in weight even if they are the same or even slower speeds. Other options include putting multiple processors on a single chip.

THE LAW OF MASS DIGITAL STORAGE

A second technology driver of IT infrastructure change is the Law of Mass Digital Storage. The world produces as much as 5 exabytes of unique information per year (an exabyte is a billion gigabytes, or 1018 bytes). The amount of digital information is roughly doubling every year (Lyman and Varian, 2003). Almost all of this information

FIGURE 4-5 Examples of nanotubes.



Nanotubes are tiny tubes about 10,000 times thinner than a human hair. They consist of rolled up sheets of carbon hexagons. Discovered in 1991 by researchers at NEC, they have the potential uses as minuscule wires or in ultrasmall electronic devices and are very powerful conductors of electrical current.

growth involves magnetic storage of digital data, and printed documents account for only 0.003 percent of the annual growth.

Fortunately, the cost of storing digital information is falling at an exponential rate. Figure 4-6 shows that PC hard drive capacity—beginning with a Seagate 506 in 1980 that had 5 megabytes of memory—has grown at a compound annual growth rate of 25 percent in the early years to over 60 percent a year since 1990. Today's PC hard drives have storage densities approaching 1 gigabyte per square inch and total capacities of over 200 gigabytes (IBM, Seagate).

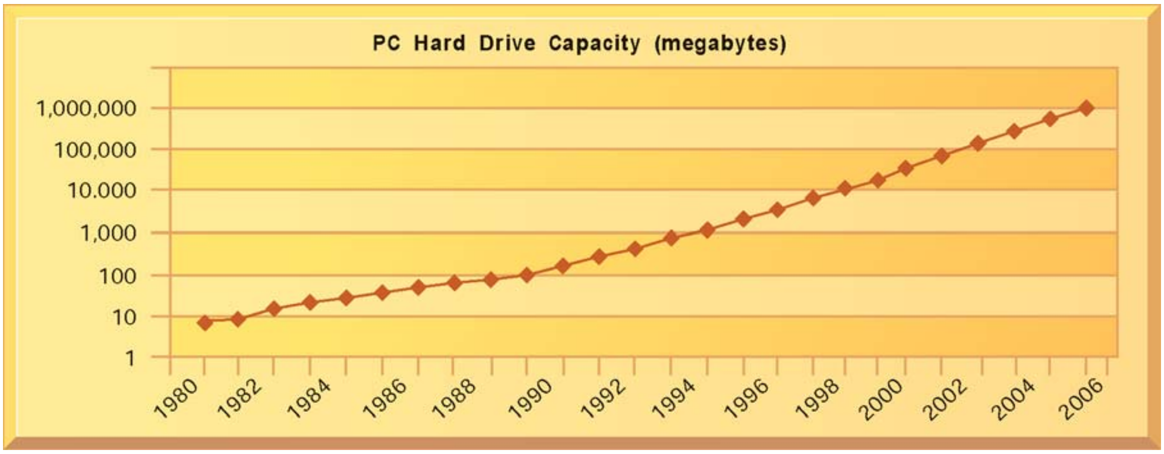
Figure 4-7 shows that the number of kilobytes that can be stored on magnetic disks for one dollar from 1950 to 2004 roughly doubled every 15 months.

METCALFE'S LAW AND NETWORK ECONOMICS

Moore's Law and the Law of Mass Storage help us understand why computing resources are now so readily available. But why do people want more computing and storage power? The economics of networks and the growth of the Internet provide some answers.

Robert Metcalfe—inventor of Ethernet local area network technology—claimed in 1970 that the value or power of a network grows exponentially as a function of the number of network members. Metcalfe and others point to the increasing returns to scale that network members receive as more and more people join the network. As the number of members in a network grows linearly, the value of the entire system grows exponentially and theoretically continues to grow forever as members increase. Demand for information technology has been driven by the social and business value of digital networks, which rapidly multiply the number of actual and potential links among network members.

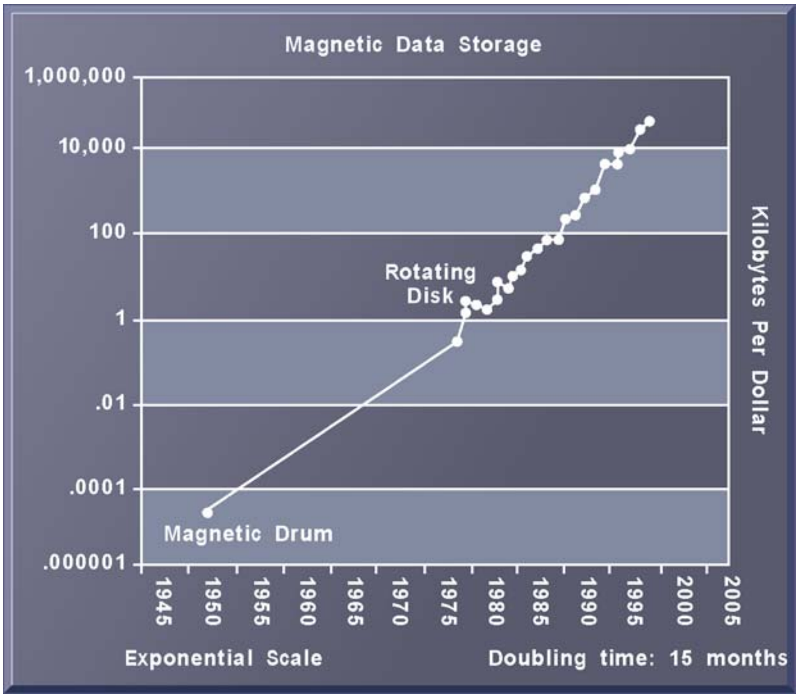
FIGURE 4-6 The capacity of hard disk drives grows exponentially, 1980–2004.



From 1980 to 1990, hard disk drive capacities for PCs grew at the rate of 25 percent annual compound growth, but after 1990 growth accelerated to more than 65 percent each year.

Source: Authors.

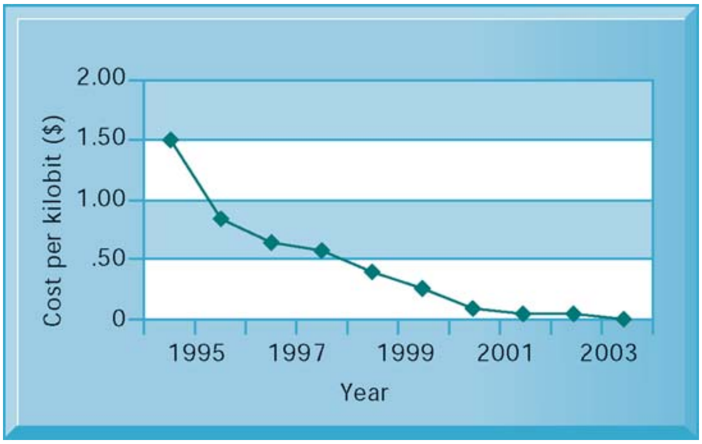
FIGURE 4-7 The cost of storing data declines exponentially, 1950–2004.



Since the first magnetic storage device was used in 1955, the cost of storing a kilobyte of data has fallen exponentially, doubling the amount of digital storage for each dollar expended every 15 months on average.

Source: "Exponential Growth an Illusion?: Response to Ilkka Tuomi," by Ray Kurzweil, KurzweilAI.net, September 23, 2003. Used with permission.

FIGURE 4-8 Exponential declines in Internet communications costs.



One reason for the growth in the Internet population is the rapid decline in Internet connection and overall communication costs. The cost per kilobit of Internet access has fallen exponentially since 1995. Digital Subscriber Line (DSL) and cable modems now deliver a kilobit of communication for a retail price of around 2 cents.

Source: Authors.

DECLINING COMMUNICATIONS COSTS AND THE INTERNET

A fourth technology driver transforming IT infrastructure is the rapid decline in the costs of communication and the exponential growth in the size of the Internet. An estimated 1 billion people worldwide now have Internet access, and over 250 million Web host computers exist in the United States. Figure 4-8 illustrates the exponentially declining cost of communication both over the Internet and over telephone networks (which increasingly are based on the Internet). As communication costs fall toward a very small number and approach 0, utilization of communication and computing facilities explodes.

To take advantage of the business value associated with the Internet, firms must greatly expand their Internet connections, including wireless connectivity, and greatly expand the power of their client/server networks, desktop clients, and mobile computing devices. There is every reason to believe these trends will continue.

STANDARDS AND NETWORK EFFECTS

Today's enterprise infrastructure and Internet computing would be impossible—both now and in the future—without agreements among manufacturers and widespread consumer acceptance of technology standards. Technology standards are specifications that establish the compatibility of products and the ability to communicate in a network (Stango, 2004).

Technology standards unleash powerful economies of scale and result in price declines as manufacturers focus on the products built to a single standard. Without these economies of scale, computing of any sort would be far more expensive than is currently the case. Table 4-2 describes some important standards that have shaped IT infrastructure.

Beginning in the 1990s, corporations started moving toward standard computing and communications platforms. The Wintel PC with the Windows operating system and Microsoft Office desktop productivity applications became the standard desktop and mobile client computing platform. Widespread adoption of Unix as the enterprise server operating system of choice made possible the replacement of proprietary and expensive mainframe infrastructure. In telecommunications, the Ethernet standard enabled PCs to connect together in small local area networks, and the TCP/IP standard enabled these LANs to be connected into firmwide networks, and ultimately, to the Internet.

TABLE 4-2 Some Important Standards in Computing

Standard	Significance
American Standard Code for Information Interchange (ASCII)(1958)	Made it possible for computer machines from different manufacturers to exchange data; later used as the universal language linking input and output devices such as keyboards and mice to computers. Adopted by the American National Standards Institute in 1963.
Common Business Oriented Language (COBOL) (1959)	An easy-to-use software language that greatly expanded the ability of programmers to write business-related programs and reduced the cost of software. Sponsored by the Defense Department in 1959.
Unix (1969–1975)	A powerful multitasking, multiuser, portable operating system initially developed at Bell Labs (1969) and later released for use by others (1975). It operates on a wide variety of computers from different manufacturers. Adopted by Sun, IBM, HP, and others in the 1980s and became the most widely used enterprise-level operating system.
Transmission Control Protocol/Internet Protocol (TCP/IP) (1974)	Suite of communications protocols and a common addressing scheme that enables millions of computers to connect together in one giant global network (the Internet). Later, it was used as the default networking protocol suite for local area networks and intranets. Developed in the early 1970s for the U.S. Department of Defense.
Ethernet (1973)	A network standard for connecting desktop computers into local area networks that enabled the widespread adoption of client/server computing and local area networks and further stimulated the adoption of personal computers.
IBM/Microsoft/Intel Personal Computer (1981)	The standard Wintel design for personal desktop computing based on standard Intel processors and other standard devices, Microsoft DOS, and later Windows software. The emergence of this standard, low-cost product laid the foundation for a 25-year period of explosive growth in computing throughout all organizations around the globe. Today, more than 1 billion PCs power business and government activities every day.
World Wide Web (1989–1993)	Standards for storing, retrieving, formatting, and displaying information as a worldwide web of electronic pages incorporating text, graphics, audio, and video enables the creation of a global repository of billions of Web pages by 2004.