INFORMATION TECHNOLOGY INDUSTRY

The information technology (IT) industry is defined by rapid growth, declining costs, and intense pressure to continuously advance. During the last several decades, the trend toward sustained increases in computer processing power, storage capacity, communications bandwidth, Internet usage, and other factors have been driven by strong domestic and international market demand. Simultaneously this strong demand has created trends of declining product size, cost, and useful life, contrary productivity trends in product capacity and power, and human effects on technological knowledge and skills. As a result world information societies have restructured to compete in a now global economic market. Knowledge workers, who are the main users of information technology, significantly outnumber blue-collar workers, agricultural workers, and manufacturing industry work force. A major technology paradigm has evolved which suggests that physical limitations need not constrain the development of new ideas. Rather than planning within current technological constraints, those in the IT industry are proceeding as though the necessary technologies will be invented in time to implement these ideas. They frequently are.

GENERAL TRENDS IN INFORMATION TECHNOLOGY

Product trends in the IT industry provide substance to this optimism. Figure 1, which plots related computer technology metric trends on a common scale, illustrates exponential growth. Note that computer processing speed, storage capacity, computer memory, and communication bandwidth all exhibit similar growth characteristics. Earlier technologies, such as the telephone, radically changed the structure of the world economy and social infrastructure. With the telephone, information became much more democratized, instantaneous worldwide communication developed. Subsequent improvements have continued to expand its information-carrying capacity. However, many computer-related technologies introduced decades after the telephone are growing significantly faster. This increase in growth portends even faster changes and transformations of our social environment, suggesting that organizations now detect and adapt to new technologies at comparable rates, no longer gauged by established stan-

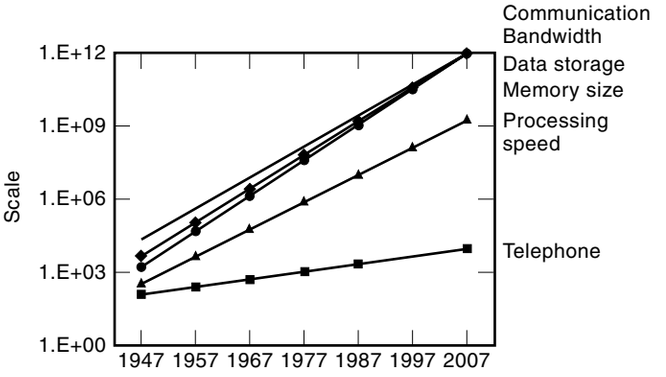

Figure 1. Information technology capacity is exponentially increasing (Data source: US Department of Commerce).

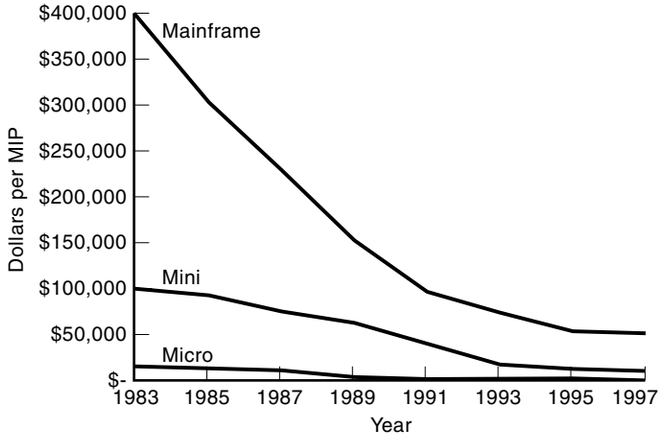

Figure 2. Rapidly falling prices in the computer retail market (Data source: US Department of Commerce).

dards. To reinforce this issue, Fig. 2 illustrates declining cost per MIP (millions of instructions), executed per second, for mainframe computers, minicomputers, and microcomputers over the past 15 years (3). In addition Fig. 3 denotes an important parallel trend: the exponentially declining cost of RAM. As of early 1998 a megabyte of PC RAM ranged in price from approximately $3.00 to $1.50 per megabyte depending on the product source and its performance requirements (30).

As for software trends, distributed computing has given rise to technology end users building their own systems. In effect, end users have become information technology islands independent of the enterprise IT department. This end-user focus has seen IT evolve from a centralized service to a decentralized software environment. Currently, distributed software concerns are driving the distributed paradigm to transition into a hybrid centralized/decentralized form. Not only is software supporting user Internet applications, electronic commerce, and global business, but also virtual system and database control are becoming more centralized, regardless of physical location.

The combination of increasing IT performance trends across the entire range of technologies, in conjunction with their pervasive public application at low-cost, may be driving a demand that will culminate in a new societal requirement—that most citizens be not just computer literate but computer skilled.

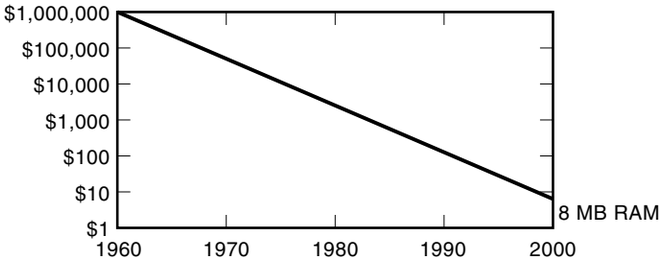

Figure 3. Rapidly declining prices in computer memory (Data source: US Department of Commerce).

Moore's Law

Gordon Moore, a visionary scientist with Intel Corporation, first observed in 1965 a doubling of transistor density on a manufactured die every year. In fact he soon made both an observation and a benchmark prediction: that the semiconductor industry would be able to continue this miniaturization trend by doubling the number of transistors that could be imprinted onto a computer wafer every 18 months—effectively promising that the industry could increase the capacity of computer components to perpetuity. More than 30 years later, Moore's law still holds and can be mathematically determined to continue through 2018 (42). This exponential increase in transistor density is the primary price driver behind transistor costs, which have fallen six orders of magnitude since being invented in 1947. Because the wafers used to produce the computer chips represent a fixed cost (approximately $1 billion per acre, according to Intel), continuing cost reduction in components depends on continuing transistor miniaturization. However, reduced cost is only one benefit. Smaller transistors operate faster, generate less heat, occupy less space, and integrate with more components on a single chip. Figure 4 demonstrates a tangible result of Moore's law, charting the increasing number of transistors per computer chip for various computer products over a 25-year period.

Living in the Information Age, Emergence of the Knowledge Age, and Dependence on Technology

Civilization has passed through major developmental phases which may be characterized by the technologies that predominated during those phases. Following human prehistory, the Agricultural Age generated agricultural technologies, marked first by the invention of the plow perhaps 10 of 15 thousand years ago. Most people survived by agriculturally related productivity during this period. The Industrial Age began in Europe around 1750, marked by what is often called the Industrial Revolution. The Industrial Age was characterized by mass production of products which created huge economies of

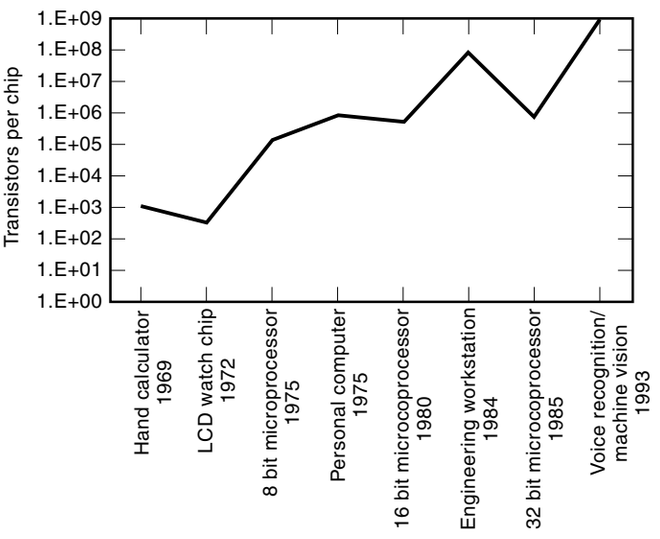

Figure 4. The increasing performance trends of the IT Industry are evident by the increasing numbers of transistors per chip with each new product (Data source: US Department of Commerce).

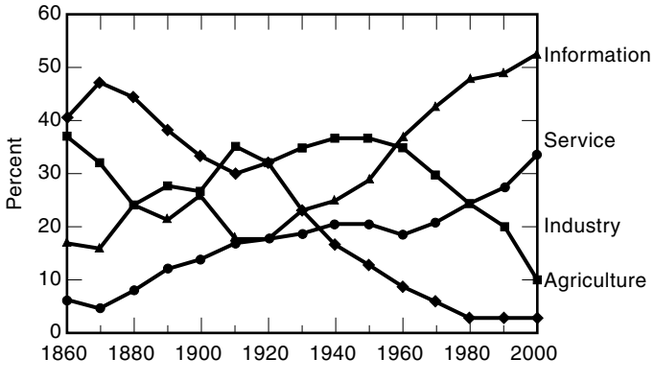

Figure 5. The four sectors of labor force, 1860–2000, show that information and service jobs will soon comprise more than 80% of the economy (Data source: US Department of Commerce, US Department of Labor).

scale, combining automated manufacturing, mechanized labor, and interchangeable parts. In industrialized countries, social and economic environments radically changed when large numbers of people migrated to industrial centers from the rural farms and grazing lands. Led by futurist Alvin Toffler (37), most people believe that industrialized countries now exist in an Information Age which drives the world economy. For these information-dependent societies, the Information Age began in the early 1960s with the advent of the computer and information systems. Since then, most contemporary businesses have become so dependent on information technology that they must technologically align their functions to compete with others who use IT to achieve a competitive advantage over them. Because most people currently are employed business-related jobs, the effects of IT have rippled from the employment sector throughout society with surprising pervasiveness, resulting in a new social paradigm. The Information Age is supported by US census data in Fig. 5, which shows the steady decline in the agricultural and industrial labor forces (3). The decline is punctuated by a corresponding dominance of information-oriented jobs, which comprise over 50% of the work force, and is followed by service-oriented jobs, which should reach 35% by the year 2000. The data suggest that an astounding 80% of US employees soon will be involved in informational-type jobs, with a heavy computerization of both the agricultural and industrial sectors being necessary to sustain them (36,37).

However, mere quantity and pervasiveness of information in industry and society does not speak to its efficient utilization. A phenomenon known as information overload, which occurs when the volume of information exceeds an individual's or system's capacity to absorb it, suggests we are at the limits of the Information Age and at the threshold of another age known as the Knowledge Age. Interest in management of knowledge resources has begun to rapidly mature, especially since so many people are involved with extracting knowledge from information. Nearly 75% of the US Gross Domestic Product is generated by the various knowledge and IT sectors of the economy (46). Observers predict that the Knowledge Age will be characterized not by information but by the synthesis of information into knowledge of all kinds—where technology is viewed less as a possible substitute for human brain-power but as a trainable, intelligent supplement. Knowledge will be assimilated, logically aggregated, preserved, maintained, and easily and instantaneously accessed by all elements of society. Of course the Knowledge Age paradigm rests on advances in the various applied areas of IT. A discussion of major IT economic sectors follows.

COMPUTER HARDWARE

As in other IT economic sectors, sales of computer hardware have been driven by strong demand and sales for IT products. Rapid advances in computer capacity, semiconductor technology, computer power, memory, storage, and communications have transformed the industry and its users. This swift evolution has transformed the IT market from (1) a centralized, mainframe-oriented, and dominated by hardware marked, to (2) a decentralized, client/server oriented, and distributed software-dominated market, to (3) a hybrid-centralized market, with an Internet backbone connecting businesses all over the world, and integrated into a single hardware/software/communications infrastructure (31). The continuing convergence of all IT areas around the Internet/Intranet technology is contributing to the formation of a single, massive global IT infrastructure. However, the computer platforms dominating this area are not the massive structures built from iron and silicone but powerful and comparatively small servers, workstations, and desktop PCs possessing resources that dwarf the capacities of earlier-era mainframe units at a fraction of the cost.

In Fig. 6, the United States continues to lead in international computer hardware sales, although its market share is declining by about 1% per year (11). Japan, Singapore, and Taiwan, the primary competing countries, are characterized by heavy national and private investment into IT research and development (R&D). The latter two show modest annual gains in world market share. Some experts predict the declining US market trend may soon reverse itself, owing a reemergence of US semiconductor and computer manufacturers in the global market. Under this new structure, new technologies are developed in the United States and for a short period are sold at a premium either domestically or in foreign markets until they are replaced by even newer products. For instance, US computer firms purchase about 62% of their semi-

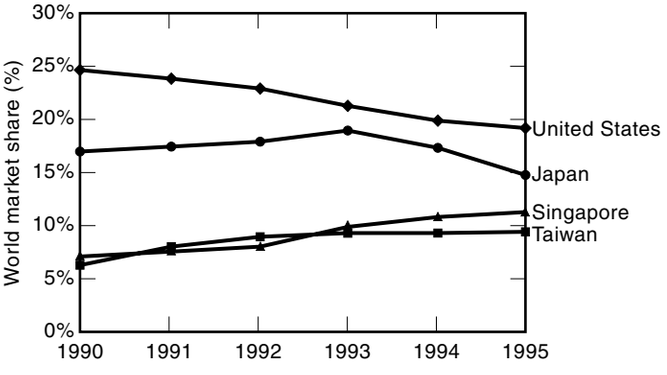

Figure 6. The United States and Japan are loosing global market share in hardware sales to other countries (Data source: US Department of Commerce).

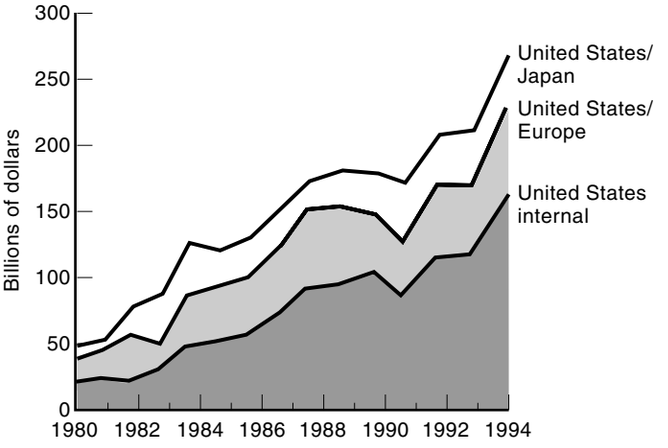

Figure 7. The United States concentrates most of its research and development alliances within its borders (Data source: US National Science Foundation).

conductor needs from other US firms (21). Figure 7 yields insight into current computer hardware R&D alliances, where US manufacturers have dramatically increased their R&D expenditures both internally and with non–US firms abroad. Once the new computer products have established themselves in the world market, manufacturing of many of these mature technologies will move to foreign countries, characteristically in the Pacific Rim, where the labor costs are much lower than in the United States. Thus Malaysia, China, Philippines, and other countries generally extend the product market life until the next mature technology arrives, while remaining one or two product generations behind US manufacturers.

However, the market complexion is becoming more complicated due to the growth of partnerships between international manufacturers and government sponsorship of R&D efforts by home companies. Most countries, including Japan and the United States, frequently sponsor international alliances with foreign companies—alliances that also give these companies more ready access to domestic markets. In addition firms are transforming their internal structures to adapt to the new market environment, moving back toward more vertically integrated structures and away from the highly focused horizontal markets of the past 15 years (17). This strategy lay at the heart of Compac Computer's recent purchase of Digital Equipment Corporation. Consequently many companies have begun to bundle computer hardware, software, communications, and services to meet market demand for one-stop computer product shopping. Differentiation of the computer hardware sector becomes more difficult on the demand side, since the IT convergence around Internet technologies blurs the true significance of any separate IT area. Also intra-market synergies may cause economic and technological ripples throughout.

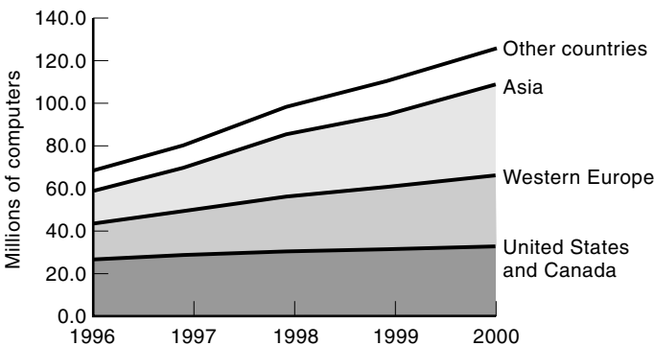

Figure 8. Global PC shipments will eclipse 120 million computers per year by 2000 (Data source: US Department of Commerce).

United States product shipment data, shown in Fig. 8, indicate relative increases in both sales and market share of competing industry product areas. Analysis of these data characterize the viability of the product and its relative dominance over competing products. Historical US computer sales data, and estimates from the past 36 years for a variety of computer types, indicate these trends (47). Computer types covered in these data include (1) supercomputers, (2) mainframe computers, (3) minicomputers, (4) microcomputers, (5) desktop workstations, (6) word processing computers, and others. They are consolidated into the categories: mainframes (types 1 and 2), minicomputers, and microcomputers (types 4, 5, and 6). Figure 9 illustrates sales for the three categories, while Fig. 10 illustrates the same data, adjusted for inflation in 1982 dollars. Perhaps the most interesting feature is the convergence of the three computer categories into near-equal sales at about 1984. Following the introduction of microcomputers in the mid-1970s, micro sales appear to permanently reverse minicomputer market growth and temporarily usher the decline of the mainframe market. For instance, minicomputer lines show continued weakness in some areas of the market. Mainframe growth is once again strong, and it is projected to remain so for the next five years. IBM is currently enjoying one of its strongest markets ever. Home sales occupy about 20% of the microcomputer market. Excluding home sales, microcomputer sales still occupy about 40% of the total computer hardware market, compared with about 25% for mainframes and minicomputers. Total shipments of computer equipment eclipsed $90 billion, rising at an annual rate of 14% since 1992 (32,41).

High-Performance Computers

The technology of computing has gone through two eras: sequential and parallel. Sequential computing, proposed by Von Neumann in 1944, has made tremendous progress and embraced many different new technologies. However, sequential computing presents physical limitations that can be resolved through parallel computing. High-end parallel computing comprises two main architectures, parallel vector processing (PVP) and massively parallel processing (MPP). PVP computers, such as those produced by companies like Cray, Fujitsu, and IBM, are cluster computers that have traditionally occupied the high end of the supercomputing market (16,24). These computers typically contain a complex integration of power-intensive and extremely dense circuitry, liquid coolant systems, large shared memories, large word and bus sizes, and a maximum of several dozen highly sophisticated processors. MPP machines represent an alternative distributed architecture that couples hundreds of comparatively low-cost processors with distributed memories, CMOS (complementary-metal-oxide-semiconductor) technologies, and no special

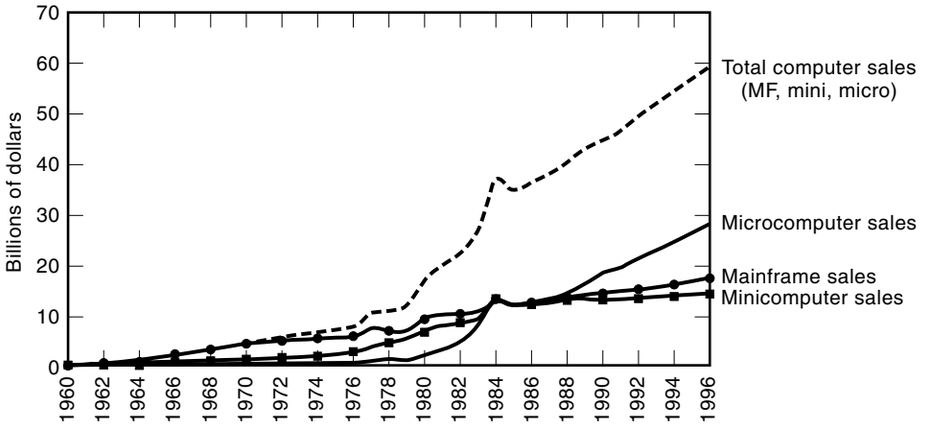

Figure 9. Total computer hardware sales have accelerated since the late 1970s (Data source: US Department of Commerce).

cooling requirements. Although high-performance computing currently deals with gigaflop computers (capable of executing billions of instructions per second) the US Department of Energy is currently sponsoring approximately $250 million to develop teraflop (trillions of instructions per second) computers with such companies as Cray Research, IBM, and Intel Corporation. In addition the Federal High-Performance Computing and Communications program sponsors similar research in industry and academia with an annual budget of about $1 billion (26). As with other kinds of computer hardware, the IT integration trend around Internet technology is driving a gradual shift in emphasis from isolated megaprocessing units to network-integrated computing, with broader availability of computing power.

Generally, high-performance computing is not available to mainstream computer users. However, assorted parallel computing capabilities are available in servers and high-end workstations. Integrated circuitry, motherboards, and peripherals all implement parallel support functions. At a higher level, both Unix and Windows NT server operating systems, for example, support two or more processors. Thus far, a main inhibitor keeping parallel computing from entering the mainstream is the lack of intelligent, distributed software and innovative architecture designs, which can be integrated into sequential computing environments. Currently most parallel software fails to fully exploit multiprocessing environments and still lacks generality, portability, standardization, and adaptability.

The current trend in parallel computing indicate that the future of parallel computing will be at the global level in a form called *cluster computing*. Cluster computing is the result of microprocessor technology and high-speed networking. It is a network of individual computers capable of communicating with each other when needed, and being able to work on their own tasks or share the task execution among multiple platforms. This form of parallel computations seems most logical because it is easily scalable and most robust.

Mainframe Computers

Figures 9 and 10, specifically in the period since 1996, illustrate that mainframes are regaining market prominence. Until recently the mainframe market was characterized by declining sales and declining usage. However, trillions of lines of software continue to operate satisfactorily on mainframes, and when considering the cost and risk of redeploying these established systems to new platforms, mainframes offer a comparatively attractive, reliable, cost-effective alternative. Gartner and other consulting groups estimate that yearly costs for networked PCs may total more than $10,000 each to support and maintain–several times the cost of mainframe services (14). Although Microsoft estimates a lower figure, a

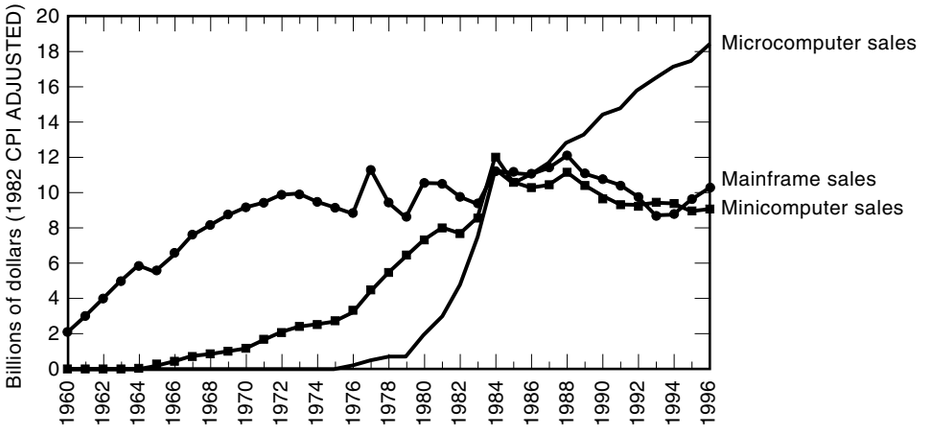

Figure 10. Computer sales, adjusted for inflation, show microcomputers as the growth area (Data source: US Department of Commerce).

narrowly defined integration around Microsoft technologies is required to achieve the savings. Currently most companies possess a spectrum of technologies. Following the temporary mainframe decline, corporate networks evolved a critical role for the mainframe as a database server within the client/server environment. This third tier of the client/server architecture physically groups mainframe servers and network servers.

Although mainframes are no longer the central attraction, as they were through the 1970s and 1980s, they are now part of a integrated management and control strategy that includes mainframes, serves, and other technologies. Furthermore IBM, Hewlett-Packard, MCI, and other companies are expanding computer and information services to provide their clients with total computer-management solutions, mainframe maintenance and upgrades, as well as other servers in this hybrid-centralized environment. Technology is advancing in mainframes just as rapidly as it is advancing in other supporting areas of the computer market. In addition, according to the Meta Group, mainframe MIPS demand will grow 45% annually through the year 2000 (44). Estimates suggest that by 2004 mainframes will comprise approximately 44% of the scalable-server MIPS in the marketplace, while Unix systems will provide 39% and NT servers will provide about 17%.

Personal Computers

The personal computer (PC) industry in the United States is comprised of thousands of PC manufacturers, peripheral manufacturers, assemblers, system integrators, retailers, wholesalers, resellers, and service consultants. While over 85% of businesses in the United States are heavy users of PC technology, PCs have also been purchased by 40% of US households and by 25% of households in Western Europe. Industry observers speculate that the market penetration for PCs has reached saturation at the standard $2000 per unit level, making further penetration possible only if the per-unit price drops significantly. However, it currently appears relatively stable, since customers opt to fit additional features such as larger memory and disk drives within a stationary price range. New technologies, such as (Digital VideoDisk) DVD-ROM drives, whose disks can hold seven times the data of CD-ROM disks, may marginally boost sales in 1998 but are still new and will be priced as discretionary premium items. Industry observers predict that by 2000, over 120 million units will be shipped annually (2). Figure 8 shows that the largest shares of the global market are held by North American manufacturers, followed closely by Asian and Western European firms. The largest US market share for PCs is in desktop and server computer sales with over 32 million units projected by 2000, with business units projected at 28 million. Figures 9 and 10 clearly illustrate that microprocessor computer sales, of which 95% are personal computers, dominate the US market.

PC platform evolution has been a rapid, eventful convergence around a few technologies. They evolved from an original thin specialty market for hobbyists, consisting of dozens of different, incompatible, and limited computer models, into a global industrial market dominated by a single platform standard. This platform, commonly referred to as the *de facto* WinTel standard, is focused around the Intel ×86 CPU and the Microsoft Windows operating system. Former pretenders to the throne include the much-weakened Apple Computer's versatile Macintosh line. A new product, Oracle's Network Computer, or NC, is attempting to break the WinTel grip by offering a low-cost, simplified computing approach, which we will discuss later. Parallel computing features are also making their way to the desktop, since user and industry technologies are now converging (38). Now, PCs, mainframe computers, and supercomputers are now using the same or similar chip designs. This trend indicates that during the next few years, primarily desktop computers will become pervasively parallel, having the capability of easily augmenting capacity by adding multiple processors. All of these alternative platforms have currently settled into market niches, and their vendors are digging in for the onslaught that Microsoft is mounting to marry the platform with the Internet.

Part of the problem enters around Microsoft's Internet Explorer (IE), which Microsoft has inextricably integrated into its Windows operating system. The other part is that Microsoft holds a virtual monopoly in the PC operating system environment, where the Windows operating system is now installed on about 90% of the world's computers. With this tremendous advantage for Microsoft already in place, many WinTel manufacturers claim that Microsoft has compelled them to include the IE with each new installation of Windows—a charge supported by the US Justice Department. However, the complaints and legal maneuvers already may be too late. As demonstrated by Windows market share, the strategy has been witheringly successful. The IE's primary competitor, Netscape's Communicator, has dropped precipitously in market share from a previous 85% of the Internet browser market in 1995 to less than 40% in 1998, while IE now commands the opposing and upwardly trending 60%. As noted elsewhere in this article, the converging IT markets have made highly focused manufacturers such as Netscape vulnerable, especially if they have little vertical integration in their value chains (18).

Despite and perhaps because of the *de facto* WinTel standard, the PC industry is highly competitive. During the late 1990s, market growth slowed to 15% from the remarkable 30% annual rates of the mid-1990s. Not surprisingly, the industry is also consolidating, as indicated by the market share enjoyed by the top 10 manufacturers, which has risen to 65% from 56% in 1990 (41,42). Because volume PC sales to large businesses are now leveling off, vendors have evolved new marketing strategies to pursue growth opportunities in homes, small businesses, mobile computing, and schools. Profit margins have become perilously thin, driven by consumer expectations of historically declining prices and subjecting them to sudden financial hardships notwithstanding being in a growth market. In many areas of the United States, competition is so intense that PC manufacturers make virtually no profit at all, especially when considering overhead, support, and warranty costs. Therefore current survival in the PC manufacturing market requires broad product lines, low prices, quality service, established customers, and strategic alliances to both fill in gaps and broaden prospects for securing new clients.

Overall, the number of installed PCs is expected to increase to 400 million worldwide, with 200 million of those being in the United States and nearly 100 million in US homes, according to the Gartner Group (14). However, the market will blur as computing pervades society with the Internet

global network. Mobile computing alternatives will result in people using computers in surprising situations: remote monitoring and control of homes, security systems, vending systems, entertainment, and on and on. In addition, multimedia will become as necessary a part of the computing environment as the Windows interface.

Multimedia Hardware

Most PCs now possess sophisticated Graphical User Interface (GUI) and multimedia capabilities. The hardware portion of the multimedia market, estimated at $94 billion in 1988 (23), is comprised of the PC platform, the multimedia boards (with sound and 3D graphics), and peripherals (CD and DVD-ROMS, hard drives, joysticks, monitor technologies etc.). Lower unit costs has made the addition of sophisticated interfaces and multimedia systems feasible and desirable for the average user. As a result the PC is evolving in the direction of a home-entertainment (or "infotainment") device with industrial-strength commercial resources. Now PCs are being manufactured with new multimedia-extended (MMX) technology and three-dimensional graphics features—features that not only enhance PC capability to render complex game effects in real time but also integrate these same features into the platform standard for commercial use in the business environment. Sound potential in applications for the PC also is significant. Speech-recognition software can now take dictation, text-reading software can read for the blind, and adaptive multimedia sound can perform sophisticated information cues along a nonvisual human communication channel. Properly integrated with 3D graphics, multimedia business applications may become the norm in presenting information intuitively and enhancing both productivity and efficiency. In the educational venue, these features suggest exciting and compelling learning scenarios for students beyond the pages of printed text. When these features are viewed in concert with the intranet technology influences on the corporate network environment, multimedia is poised to become an important part of the business tool set during the first part of the twenty-first century.

COMPUTER SOFTWARE

Computer software represents one of the most stimulating and visible areas of the IT industry. No longer the exclusive domain of specialists, software in many forms has become accessible by the masses and applicable to an endless selection of tasks. The popularity of personal computers over the past 15 years has directly resulted in new technologies that include graphical user interfaces (GUIs) and multimedia (42). It has pushed the computer hardware industry to deliver extraordinary computing power, memory, and other resources available to the office and home desktop that can exploit innovative software applications demanded by consumers. Software developers are attempting to maintain pace with both market demand and new hardware technologies by anticipating and exploiting developments shortly after they reach the market. Integration of Internet technologies represents a major new direction of end-user accessibility. For instance, Internet Explorer integrates with desktop interfaces so that computer users can more easily master and exploit the power of their computers and networks without significant technical

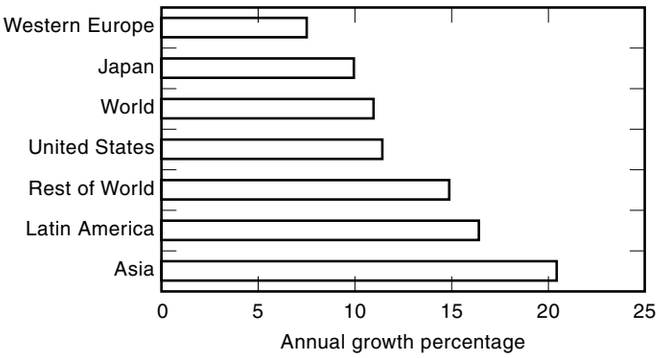

Figure 11. In the world software market, Asia is experiencing annual growth of over 20% (Data source: US Department of Commerce).

expertise. Office productivity packages that include spreadsheets, desktop databases, word processors, and presentation packages now come equipped with Internet features as well.

The software industry has remained strong, with significant growth in the United States and throughout the world. Annual software market growth in the global environment, as seen in Fig. 11, indicates that Asia and Latin America exhibit the most new opportunities for software developers and vendors. Software development, both general and parallel, has lagged the exponential advances in hardware. Many opportunities for fundamental advances exist in software engineering, including design, validation, maintenance, and automated development theory and tools that are required to close the gap. If industry trends hold, US packaged software market will continue as the largest part of the $109 billion global market, at $46 billion. Figure 12 lists IBM as the world's largest software supplier holding 13% of world market share, with Microsoft closing the gap at 9%. Windows application software claimed over 80%, or $8.5 billion, of the $10.6 billion market. Desktop publishing and utility software grew at a 60% rate, graphics software at 48%, languages and tools at 38%, and database software at 33%. Indicating the importance of the GUI to purchasers, Windows software increased at a 70% rate, while DOS software declined 51%. DOS soft-

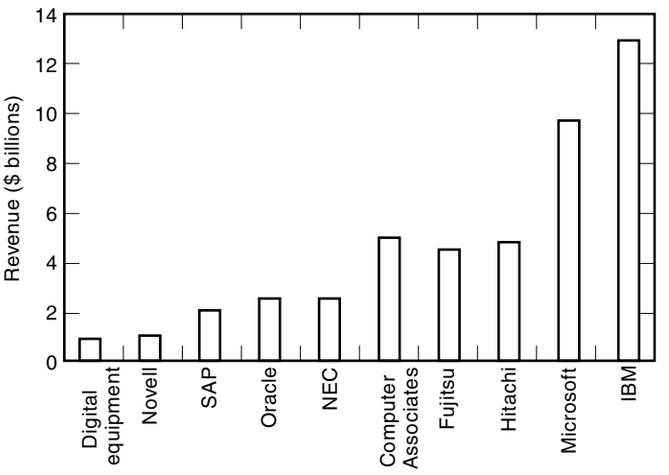

Figure 12. IBM and Microsoft are the leading software suppliers (Data source: US Department of Commerce).

ware will be virtually nonexistent in the business environment by 2000 (21).

As an employer, the US software industry has more than tripled in size during the past 10 years. During 1996, more than 200,000 people worked in the industry. At its current growth rate of 13%, the industry will employ approximately 325,000 people by 2000. As a result of tremendous demand for software development and services, in addition to high salaries in the United States firms have begun to seek lower-salaried workers overseas. Since 1990 foreign development expanded from India to Malaysia, China, Brazil, Russia, and former Eastern Block countries, primarily for development of customized software (11,34). However, despite its popularity as an alternative to the employment challenges experienced by domestic firms, offshore development introduces other issues. Cultural differences, remoteness from the client, difficulties in adjusting to changing requirements, security issues, and control issues all add complexity to the management equation.

Packaged Software

Packaged software, consisting of system software, application tools, and application solutions, surpassed $125 billion in sales during 1997 and is expected to surpass $221 billion by 2002. Operating system software consists of operating systems, OS enhancements, and facility management tools. Application tools include data management, data manipulation, data access and retrieval, and system development software. Application solutions include industry and office applications, with office suites such as Microsoft Office and Corel Perfect Office. According to the US Department of Commerce, worldwide operating systems sales are expected to grow from $23.7 billion in 1996 to 46.8 billion in 2002, application tools from $31.3 billion from 1996 to $66 billion in 2002, and application solutions from $54.2 billion in 1996 to $98.2 in 2002. The US software market is estimated at $58.5 million, or about 46% of the world market. US operating system sales are expected to grow from $12.6 billion in 1997 to $21.3 billion in 2002, application tools from $16.1 billion in 1997 to $30.5 billion in 2002, and application solutions from $29.8 billion in 1997 to $51.4 billion in 2002 (41).

CAD/CAM/CAE

Other areas of the software industry include CAD/CAM/CAE (computer-aided design, computer-aided manufacturing, computer-aided engineering), architectural and engineering systems, and geographic information systems (GIS). Software in these areas require high-performance workstations and computing to render and manipulate complex images in an online environment. In addition these applications typically require huge amounts of data and versatile databases. Markets for these software tools are healthy, with CAD/CAM/CAE worldwide sales estimated at approximately $7.8 billion in 1997, and the other areas at somewhat lesser levels (41).

Multimedia Software

Multimedia computer technologies combine multiple presentation media such as text, graphics, full-motion video, sound, and voice on a computer platform. Multimedia computing was a main reason that approximately 40% of US households now own a personal computer. Multimedia not only provides a platform for family business and record-keeping activities, but it also serves as an entertainment center for the whole family, affording access to the Internet and its vast research resources, as well as a flexible platform for a wide variety of highly realistic games. Observers suggest that marginal computer sales due to multimedia have reached saturation, even though the price of incorporating appropriate hardware and software into a computing system may be only a few hundred dollars. Although home computer penetration has been estimated as high as 70% of professional households (2), additional price reductions and features will be necessary to approach this number. Furthermore corporate users are not heavy users of multimedia PCs, since most consider additional features such as sound and recording capabilities unnecessary or distracting and requiring additional maintenance attention.

Virtual Reality

Virtual reality (VR) systems are interactive graphical, visualization, simulation systems that mimic environments so closely that individuals often perceive they are actually part of the artificial environment. Most high-end VR systems are computer-intensive applications that require special equipment which may include sensored body suits, special gloves, stereoscopic goggles, and sound systems that immerse the user in a virtual world. The special clothing monitors various body motions, including foot, leg, arm, and head movement, feeding these data into the VR computer. Immediately the computer responds with simulated visual feedback through computer displays in the goggles, sound, and even simulated sensations through the special clothing. Lower-end VR applications use computer terminals as portholes into virual worlds, where the user can peer into and manipulate objects within that world.

VR is just beginning to be used in medical, entertainment, and educational environments. The promise of VR applications for the office is also great, especially with the evolution of Virtual Reality Markup Language (VRML), which can introduce 3D worlds viewed with an Internet browser. Military and commercial pilot systems are heavy users of VR, where pilots are immersed in highly realistic flight situations while avoiding risk to life and property. Futuristic application possibilities are endless. With VR equipment, chemists can see, touch, and model complex molecular structures, surgeons can perform complex operations from start to finish, engineers can test and retest complex automotive innovations, students can "ride" on human blood cells as they learn about the human body, communications administrators can design, monitor, and maintain data networks, and an infinite number of other applications. In spite of its obvious promise, VR is still in its infancy. It still requires significant advances in realism and usability, along with dramatic reductions in cost, before its application can become as widespread as multimedia.

On-Line Technologies

On-line technologies include Internet service providers (ISPs), on-line service providers (OSPs), and Internet content providers (World Wide Web sites). The US Department of Commerce reports that PSINet, NETCOM, UUNet, and other ISP companies experienced rapid growth in the 1990s, using flat-

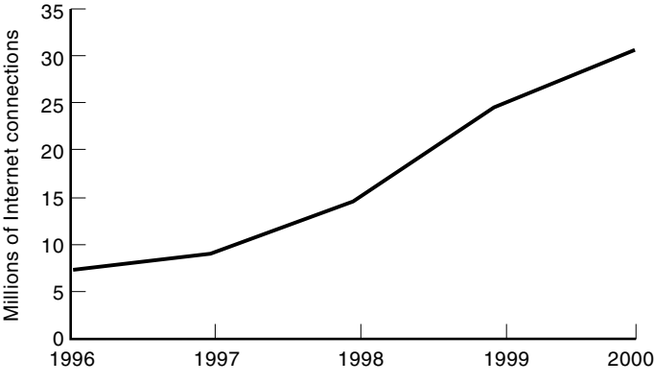

Figure 13. The number of Internet connections will triple between 1996 and 2000 (Data source: National Science Foundation).

rate fee structures and providing sites for Web pages. Other major providers include MCI/British Telecom's Concert, and Sprint/Deutche Telecom/French Telecom's GlobalOne. Regional phone companies and other ventures are also aggressively entering the ISP market. AT&T Worldnet, Microsoft, America Online, Compuserve, and Prodigy offer connection services in combination with browser software and related web services, adding an organizational structure to their service. OSPs aggregate content of other firms for subscribers into a user-friendly form. For instance, AOL provides an extensive offering of various categories and services that are maintained for subscribers. They now frequently integrate this content with direct access to the Internet, burring the boundary between ISP and OSP, especially since many firms now prefer to maintain their own Web sites and Web addresses on the Internet (33). Figure 13 shows the estimated combined growth of ISP/OSPs through 2000. Finally the convergence of computing and Internet technologies, together with the explosion in Web-authoring activity has made virtually every Web user a potential content author or provider. Although low-end authoring software is provided with browsers such as Internet Explorer or Netscape, professional-quality authoring is becoming more sophisticated, requiring professional graphics, sound, casting, technical writing, and other services. Quality Internet software development requires development techniques similar to any other distributed software project, plus additional resources to effectively reach the broad potential client base throughout the world.

ELECTRONIC TECHNOLOGIES

Electronic technology systems contain electronic components which are first manufactured separately and then assembled to form a complete system. Electronic components are used not only in computer equipment but also in telecommunications devices, household appliances, medical and manufacturing equipment, radios and televisions, automobiles, and countless other applications.

During the last decade electronic technologies, particularly in the area of integrated circuits, have become an international industry. The phenomenal growth in traditional and embedded systems across the global market is being driven by consumer demand—demand fueled by continuously decreasing component size, in conjunction with rapidly increasing component power and versatility (21). The demand also has been accompanied by fierce competition among world competitors, forcing them to emphasize efficiency in all lines of production and sales to survive. Manufacturers are particularly keen to introduce innovative technologies and product lines that will sustain growth and contribute to growth in market share. However, reduction in costs of production is also a major emphasis, where many electronic technology firms have moved their manufacturing facilities to third world countries where costs of production are low.

The outlook for US sales of electronic components is very favorable. In 1997, US manufacturers exported nearly $41 billion, and the exports in 1998 is expected to surpass $48 billion, a 12% increase over 1997. It is predicted that the US market of electronic components will grow at 13% annually from now through 2002 (40). Industry observers predict that within the next few years, the fastest growing market for the United States is in developing countries such as Eastern Europe, Russia, China, Mexico, and Singapore. Figure 14 shows world microelectronic market sales, with Japan now the leading exporter and the United States a close second, followed by Korea and Malaysia. Other government data indicate the long-term growth for electronic components is very optimistic, mainly due to computer telecommunication and the introduction of more electronic components into other lines of products such as cars and toys.

Semiconductors

Semiconductors are active electronic components capable of transmitting electricity. Semiconductors may contain one component or many (thousands or millions) integrated transistors with end-pins for interfacing with other electronic components. The end-product is called a computer chip or simply a chip. The computer industry is the largest user of semiconductors in the world. In the United States, among the more than 100 semiconductor companies, IBM, Intel, Lucent Technologies, Motorola, and Micron Technology are the industry leaders. The US Census Bureau reports that the US employment in semiconductor businesses reached 189,000 in 1995 (3,40).

Industry observers indicate that the semiconductor industry is maturing, and the product life cycle for semiconductors, such as PCs, is shrinking, which is in rival with profitability

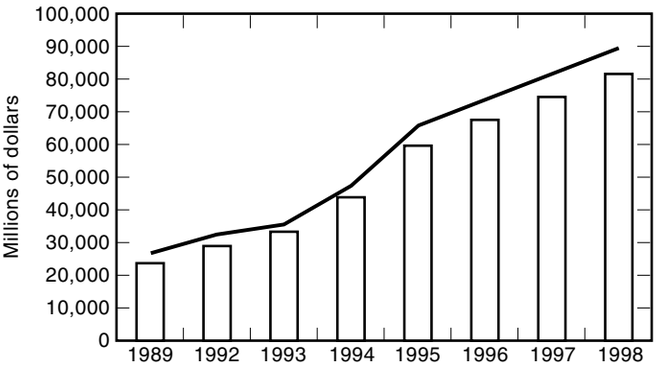

Figure 14. The semiconductor market drives advancements in informational technology (Data source: US Department of Commerce, Bureau of the Census).

and the time required to recover from the costs of design, engineering, and manufacturing. Because of this, many companies are partnering with other companies. As this trend continues, only the strongest companies will survive, in partnership with other companies, and the semiconductor industry will become monopolized by giant companies leaving no room for small size companies to grow. Industry observers predict that the worldwide consumption of semiconductors would grow at a rate of 15% through 2002, bringing the market total value to $300 billion, an increase of about 50% from 1998. The US semiconductor business is predicted to grow at a rate of 13% through 2002 (8). In summary, the next few years will show fierce competition among leading edge semiconductor companies in such areas as MOS memory, multimedia PCs, wireless communication, digital switching, digital TV, and digital camcorders.

INFORMATION SERVICES

The United States continues to be the world leader in both the consumption and production of information services. According to the 1992 US Department of Commerce data, the information services economic sector includes professional computer services (58%), network services (28%), and electronic information services (14%). In every area of IT, the United States represents the largest market for IT and provides the most IT products worldwide. The vast majority of jobs in the United States are information and service oriented, as documented by the earlier Fig. 5, making information services one of the major and fastest-growing sectors of the US economy (36).

Both domestic and international sales of information services continue to grow at about 20% per year. The growth of the information services sector is closely linked to the IT product sales and sales projections, where the production, integration, and maintenance of computer hardware, software, and communications comprise is core. Value-added services accompany IT product sales, where installation, deployment, and training services are delivered to IT clients that enable them to efficiently and effectively utilize their purchases. Longer-term services include IT consulting, outsourcing, electronic commerce, and Internet-related services. The United States continues to enjoy a large export surplus in information services, expected to pass $5 billion in 1998 (36). With IBM and Electronic Data Systems leading the way. The top ten global information services firms are listed in Fig. 15.

Convergence in the IT industry is a major driver in growth of services. While large companies tended to strive toward vertical integration (providing a full range of products and services) during the 1950s through the 1970s, they moved toward horizontal integration (providing a few extended lines of products or services) during the 1980s and 1990s. While these firms can offer, for example, a business office suite of integrated software for the PC, they would be less able to provide an integrated package of computer support and advisory services with their products. To prevent clients from having to engineer their own solutions piecemeal and to secure additional business, product and service providers now frequently engage in mergers, acquisitions, alliances, and partnerships among themselves to create full-service, integrated solutions that include their products. Examples include Microsoft's alliance with NBC to form the MSNBC News Channel and Compac's purchase of Hewlett-Packard to strengthen its ability to provide integrated computer sales and solutions to its customers.

Diversification trends in the market also affect the information services sector. For example, MCI, AT&T, Sprint, USWest, and other telecommunications firms are now offering Internet services. Cable services companies such as Cox Communications and Warner Communications are now expanding beyond cable television into Internet and telephone, as well as cellular and PCS wireless communications services. Premium cable channel entertainment companies such as HBO and Cinemax now produce some of their own content, acting much like television or movie studios. Global expenditures on software services increased from 17% of total IT services in 1985 to 27% in 1995, according to Datamation. This area, which includes consulting, programming, systems management, systems integration, facilities management, and disaster recovery services, now makes software services the largest area of spending within information services. As noted, demands for expertise to manage the rapidly changing IT market have driven steady growth and have quickly made old skill sets less valuable while placing new skill sets at a premium (4,17). Examples of new skills include client/server development and management, as well as the exploding demand for skilled Internet/intranet expertise. Because the Internet technology is constantly changing, expertise to deal with the complexities of Internet security, its interface, and the evolving tools is quickly outdated. The added task of integrating these malleable technologies with established architectures often presents as much burden for firms as it does opportunities. Custom programming overall is leveling off, probably due to the increasing selection, reliability, and flexibility of predevleoped software already available on the market, as well as vendors willing to integrate these packages into client businesses (33).

Strong international demand for computer products is an important driver in the intense demand for information services. Purchases of hardware, software, and communications are at historic highs by foreign countries. Many countries are also lowering trade barriers that further stimulate growth. However, this upward trend may have at least temporarily crested. As of early 1998, it is too early to ascertain what the full impact of weaknesses in Asian markets will be in this sector. However, given the extensive decline in asset values in markets such as Japan and Hong Kong, direct impact on computer sales is likely. International and national government regulatory legislation, such as the General Agreements on Trade in Services (GATS) in 1993 and the Telecommunications act of 1996, also contribute to change in the IT industry.

Electronic Commerce

Electronic commerce (EC) and electronic markets represent an extremely important area of the IT marketplace. While there is currently no consensus as to what comprises the electronic marketplace, EC primarily focuses on transactional services that already exist in the economy, adapted into an electronic form. Electronic data interchange (EDI) is a foundational part of EC. Comprised of protocols for effecting computer-to-computer exchanges of document-oriented data, EDI provides an alternative to mailings of paper documents which

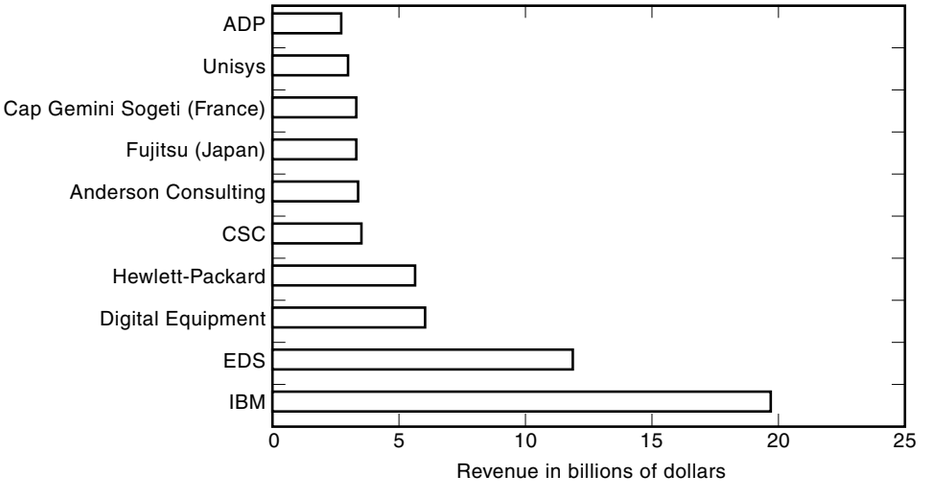

Figure 15. IBM and EDS lead the world in information services (Data source: US Department of Commerce).

include orders, invoices, inventories, reports, and other materials. However, the Internet promises to converge EC and all other related technologies, including EDI, into its domain. The Internet will do this by providing a full spectrum of services and features, not only to cooperating companies, as with EDI, but also to their customers (9,33).

Although EC marketing channels extend traditional commerce to the Internet, there still exist distinct differences between the traditional marketing world and this new medium. For instance, EC markets are not expected to replace retail stores or even act as retail outlets, they do not respond to broadcast advertising, and, as yet, are not for the risk-averse. EC sites frequently require completely different marketing and sales techniques, and hence, requires completely different approaches to customer acquisition and retention than traditional techniques. Developing an EC marketing strategy will only marginally overlap with television, radio, or published media campaigns, so good EC strategies are usually assigned their own budgets. EC markets are niche markets, providing both the capabilities and rewards for selective marketing. Finally EC markets currently perform best when treated as supplementary markets, permitting firms to selectively evolve around the computer-literate individuals inclined to use the Internet medium.

Financial institutions and specialty marketers are some of the first firms to explore EC, while Internet security firms have developed technologies to secure the transactions and credit information from packet pilferers. With the maturing of encryption techniques, a variety of payment mechanisms have emerged, from facilitating credit verification to virtual accounts that can be treated as on-line cash for Internet purchases. US Department of Commerce estimates put EC transaction volume by the year 2000 as high as $230 billion (4). As access to the Internet becomes as common as watching television (and some technology firms have developed an Internet-TV technology that combines both worlds), EC transactions will likely explode.

OTHER MAJOR TRENDS IN THE INFORMATION TECHNOLOGY INDUSTRY

This section describes other IT trends important to the industry and economy. These include patterns of centralization, technology dependence, and the Year 2000 problem.

Centralization and Decentralization Market Trends

Centralization (centralized computing) and decentralization (distributed computing) refer to the broad spectrum of computing resources. Computing resources include human computer resources, computers of all kinds, associated secondary storage devices, information resources, and communications. Observed periods of dominance in Fig. 16 and cycles of centralization and decentralization in Table 1 indicate that information technology is entering a third, hybrid cycle of centralization (47). The previous paradigm of client/server architectures has been characterized by many industry sources as a failure, due to difficulties in managing, securing, and maintaining distributed systems and their data. Additional issues include the difficulties in supporting many flavors of end-user computing, quality-control issues, financial and cost-control issues, and infrastructure-control issues. However, the current Internet and intranet wave is driving both servers and databases back into a largely centralized environment where many of the issues can be resolved. The current hybrid-centralized trend is reflective of demand driving technology. Although communications infrastructures are largely unable to support virtual centralization, trends indicate information technology is still moving in that direction.

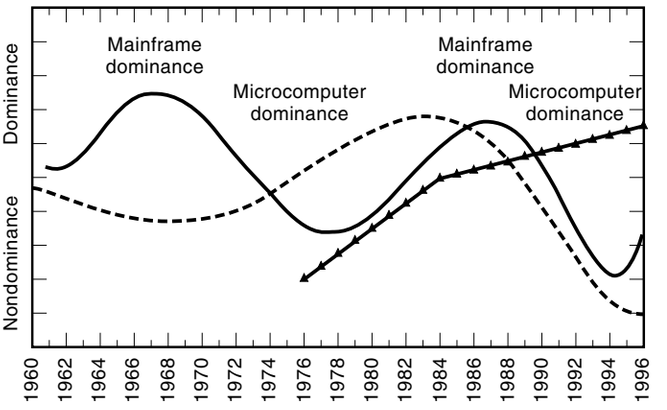

Figure 16. Microcomputers are dominating the computer market in sales and in development (Data source: Peak and Azadmanesh).

Table 1. Centralization/Decentralization Cycles and Major Factors of Influence (47)

Period	Year (approx.)	Major Features	Reasons for Change to the Period
		Cycle 1	
Centralization	1945–1978	Mainframe environment	Development of mainframe-related technology
Decentralization	1979–1984	Distributed data processing	Lower cost of minis Better performance of minis
		Cycle 2	
Centralization	1985–1989	Relational data bases	Lack of networking standards Limited computer networking Introduction of relational DBs
Decentralization	1990–1996	Client-server architectures Standard communication protocols (e.g., TCP/IP)	Corporate restructuring Growth of desktop computing Standardized networking and User autonomy
		Cycle 3	
Hybrid centralization	1997–	Support economies of scale Maturing uses of Internet Mature uses of mainframes	Desktop computer high cost of Internet/Intranet/Extranet Mainframe superservers (DB, etc.)

Logistically, users are now moving their servers into mainframe computing centers, according to recent Gartner Group information. In fact this movement has occurred practically overnight. Fewer than 1% of Gartner's large corporate clients reported servers residing in their data centers during 1994. But by 1995 nearly all corporate data centers now house servers, with 30% housing ten or more. In 1996 an estimated 60% of data centers house 10 or more server computers, in addition to mainframes—a number that had risen to 80% by 1998. Reasons given by users include:

- Data centers provide better hardware and software support than end users.
- Data centers provide better physical security (controlling access to the servers and preventing theft).
- Data center staff offer superior systems integration support.
- Data centers control costs better than end users.

The last cited reason has a double-meaning when end users succeed in transferring server support responsibility to data centers without transferring full support funding. Recent research puts the price of network-attached microcomputers much higher than mainframes. Studies have placed total cost of personal computer ownership, including network, hardware, software, and support as high as $50,000 over five years.

Year 2000 Problem

Computer hardware and software systems of all kinds have often encoded date fields with two-digit years, such as storing 1998 simply as 98. When the year 2000 arrives, a non-year 2000 compliant system would store a two-digit year as 00. Such a system that subtracts 98 from 00 would yield a negative, erroneous number. Due to the massive information flows that permeate our society, errors in date arithmetic could conceivably be propagated throughout the information technology infrastructure, causing debilitating problems in any systems that use dates. This would expose all computer hardware, software, and communications to year 2000 failure risks.

Because the pervasive use of information technology is both visible and invisible, not only mainframes and personal computers are exposed, but also information technologies embedded in cars, aircraft, credit reporting systems, tax and social security systems, telephones, entertainment systems, pacemakers, house and business security systems, emergency notification systems, health systems, and on and on. Aside from the direct failure risks, which the Gartner Group (14) estimates will range between $300 to $600 billion worldwide to correct and seriously impact corporate budgets, litigation arising from year 2000 failures is expected to multiply that cost tenfold. Some industry experts estimate that only 40% of businesses and government organization will be totally year 2000 compliant by December 1999. But it may already be too late. Virtually all resources for addressing year 2000 issues are already committed, meaning that demand and costs for attaining compliance are high and rising.

Total Cost of Computer Ownership

The Information Technology Group in 1995 estimated that desktop computing is 2.8 times more expensive than mainframe computing (31). Most experts agree that mainframe-attached terminals enjoy a significant edge over desktop computers in raw services delivered to the desktop. The total cost of ownership (TCO) was introduced during the 1990s by the Gartner Group (14). During the mid-1990s, the estimated total cost of ownership exceeded $25,000 per LAN-attached desktop unit over five years. By 1997 the cost had dropped to less than half that amount, largely due to efficiencies that include centralized management of desktop computers and the associated economies of scale. Further reductions are projected for NCs, or network computers, which depend heavily on servers for their capacity; similar to terminals attached to

that are mainframe computers. Larry Ellison, CEO of Oracle, predicts a bright future for NCs, while Microsoft CEO Bill Gates debunks them, suggesting that NC stands for "not compatible." Currently experts are also divided on the validity of TCO, which critics allege it (1) averages costs across diverse computer applications, (2) emphasizes "futz" costs, which is lost employee productivity due tinkering with the PC and its systems, and (3) fails to accurately count numerous organizational inefficiencies (29).

The Technology Trap

James Burke (15) describes implications of societal acceptance and application of technology as a two-edged sword. While our society benefits immeasurably from technology, its members also live in peril of it. Still we have become incapable of living without technology. Having instant and ubiquitous access to electronic information throughout the world additionally contributes to complexity at the workplace and continuous exposure to world economic fluctuations. For people in the industrialized world, life without technologies such as running water, electricity, automotive transportation, telephones, or even radio, television, and computers would be unimaginable.

General acceptance and use of an information technology may have unintended consequences. Because these information technologies are commonly available, they have introduced new vulnerabilities by exposing all of their users to common risks, perpetuating vulnerabilities to many individuals, and potentially multiplying effects to millions of people who do not even directly use them. For instance, failures in a commonly used airline reservation would inconvenience reservationists, to be sure. However, the same failure could potentially disrupt airline transportation worldwide, along with mail deliveries, medical deliveries, and so on—impacting people far from the reservation desk. Failures in power-monitoring systems could leave regions without electricity. Failures in phone-switching systems could leave countries without communications. We find that we must continually replace old technology with new technology in ever-shortening cycles. Therefore we live in a kind of technology trap, having reached a level of dependence that requires technology always be available.

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INFORMATION TECHNOLOGY, SOCIAL ISSUES IN THE USE OF. See SOCIAL AND ETHICAL ASPECTS OF INFORMATION TECHNOLOGY.