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Computer Technology: State of the Art and Future Trends

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Computer Technology: State of the Art

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Abstract

Computer technology, and more broadly information technology, is invigorating a fundamental transformation in our society from an industrial economy to an information economy. A review of the short history and present state of information technology identifies two major undercurrents: the miniaturization of computer components which has produced a million-fold increase in the complexity possible in a single chip of silicon and the integration of four previously separate areas of information technology: computation, communication, databases and the user interface. Microelectronics, computer networks, data storage and user amenities are the basic technologies that support these four areas and stimulate their progress. Future trends in speech recognition, voice synthesis, artificial intelligence, expert systems, computational imaging and scientific workstations are also examined.

Key Words

Computer technology, microelectronics, imaging, artificial intelligence, computer networks, data storage.
Computer Technology: State of the Art and Future Trends

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Computer technology is invigorating a fundamental transformation in our society from an industrial economy to an information economy. John Naisbitt, author of the bestselling book *Megatrends*, predicts that the resulting information society will not displace the previous industrial and agricultural societies, but will, through automation, shift the balance to information intensive activities. Cardiology has been an information intensive activity and so it is not surprising that it was one of the earliest of the medical specialties to utilize computers in an essential way.

Other articles in this series will discuss computer applications to cardiology. Here we concentrate on the technology itself and emphasize its relationship to the information society and the breadth of the computer technology under discussion by substituting the phrase *information technology*, or as some now call it, *informatics*. This single word description of the field was originally popularized in Europe and is now gaining acceptance in the U.S.

In order to project important trends for this technology in cardiology it is desirable to review its short history and present state. Table 1 shows one summary of the five generations of information technology covering the period from the construction of the first electronic computer, ENIAC*, to 1990. Two major undercurrents are responsible for the changes evident in this table.

The first undercurrent is the steady miniaturization of computer components over

*See the Glossary at the end of this article for the full names of the many acronyms and abbreviations used herein.
the last 25 years that has produced a startling million-fold increase in the number of transistors that can be placed on a single chip of silicon at no increase in price. Moreover, speed increases have accompanied this miniaturization so that today the amount of computation that can be carried out by that single chip has grown more than ten million-fold.

The second undercurrent is the integration of the four basic areas that make up information technology: computation, communication, databases and the user interface. In the past these areas have been rudimentary or disjoint. Today we are beginning to see a few examples of the integration of all four areas within a single system. By the next decade this integrated approach will be the rule.

Basic Technologies

Today the basic technologies that support the information society correspond roughly to the four areas within information technology: the area of computation has been driven by the miracles of microelectronics; the area of communication has come of age through developments in networks; the area of databases depends upon advances in data storage technology; and the area of the user interface is making progress as a result of software advances, new input and output (IO) devices and accomplishments in artificial intelligence (AI). This last set of basic technologies we shall lump together under the heading, amenities, those devices and computer programs that make for a pleasant and productive interaction between user and machine.

Microelectronics

At the root of the information society today is the silicon chip. Its elegance, efficiency and economy have not only produced the miracles of computation well-known to all, but also fueled the transformations occurring in networks, databases and user
amenities.

As most readers know, microscopic patterns of conductors, semiconductors and insulators are laid down using photographic techniques on highly purified silicon wafers, typically from three to six inches in diameter and less than one millimeter in thickness.

The conductors have line widths of one to two micrometers in today's integrated circuit (IC) technology and a square less than 10 micrometers on a side can enclose circuitry sufficient to store a single bit of information. IC storage devices, commonly called memories, are beginning to appear with the capacity to store one million bits. These memories are fabricated by laying down the memory pattern over and over on a thin silicon wafer and subsequently dicing the wafer into about 100 chips each about one centimeter square and each containing a complete one million bit memory. Two kinds of memory chips should be distinguished, ROM and RAM. ROM stands for read only memory, information storage that cannot be altered without special procedures. RAM stands for random access memory, easily alterable memory that can access any specific location as easily as any other.

Complete computers on a single silicon chip are available that include the central processing unit (CPU), the memory (both ROM and RAM) and the IO system, but more common are microprocessors, a computer without memory and with only limited IO capability. Memory and IO chips can then be added to the microprocessor in numbers sufficient to suit a particular application. Both the single-chip computers and the microprocessors are organized along the same lines as John von Neumann proposed (1) in 1946. Most of the computers built during the intervening years have been similarly organized giving rise to the phrase "von Neumann architecture" to describe this dominant approach to computer structure. Recent research has emphasized new architectural approaches aimed at better utilization of microelectronic technology (2).
The particular microprocessor chip used in a computer system determines the family to which it belongs and the system's most basic characteristics. Well known families are those built around the Zilog Z80 chip which was used by many early personal computers (PCs), the MOS Technology 6502 chosen as the basis of the Apple II, the Intel iAPX 86 family used by the IBM PC and PC compatible machines and the Motorola 68000 family found in the Macintosh from Apple, in the Amiga from Commodore, in the 520ST from Atari and in many new, powerful workstations. Important characteristics of the processor are its clock frequency (the number of repetitions of its simplest operation that can be carried out per second), the number of bits used in the internal data pathways of the arithmetic/logic unit (ALU) and the number of bits used by the bus (external data pathways used for IO operations). The number of bits used by a data pathway is commonly called its width so a microprocessor like the Z80 is said to have an 8-bit wide ALU and also an 8-bit wide bus. A sequence of 8 bits is also called a byte so the Z80 could be said to have a one byte wide ALU and bus. The Motorola 68000 has a 32-bit wide ALU, but only a 16-bit wide bus. The more powerful Motorola 68020, a recently introduced microprocessor in the same family, has an ALU and a bus both 32-bits wide. Clock frequencies for the most recently introduced microprocessors exceed 10MHz. Wider data pathways and faster clocks lead to more powerful computers.

Miniaturization in electronics has produced almost a million-fold reduction in CPU cost in about three decades. In its present state of development this technology is called very large scale integration (VLSI). It is a remarkable achievement producing profound changes in the way computers are used in society. Once highly centralized, computers are now highly distributed. Once so expensive that the cost of their support equipment was hardly noticed, computers must now share that support equipment. Whereas digital communication was only used to bring raw input data to a centralized
computer facility, now it is used for a broad spectrum of intercomputer transactions.

Computer Networks

Early computer communication was achieved through the adaptation of voice telephone lines to digital service. A modem (a modulator/demodulator pair) converted the on/off digital signals to and from a form more suitable to the limited bandwidth of voice grade telephone lines. Telephone equipment itself, over the years since the introduction of IC devices, has been converted to digital signal processing. Thus information sent today by digital telecommunications often encounters the anomalous fate of being converted to a voice-like form only to be converted back to digital form for switching at a telephone central office. The reverse conversions take place upon leaving the central office for transmission of the digital information to its destination. As more and more of the nation’s telecommunications become fundamentally digital, the need to adapt to an outmoded communication medium will disappear. Anticipating this change, many networks have already been developed that are specialized for the transmission of digital information.

A local area network (LAN) links computers and computer resources within the premises of a company or an institution and is usually only a few blocks to a few kilometers in extent. Computers and computer resources are located at network nodes that are connected to each other by coaxial cables or glass fibers. These transmission media provide reliable, high-speed data links over the short distances involved in a LAN. This technology was pioneered at Xerox in the PaloAlto research laboratories and led to Ethernet (3), the earliest application of the LAN concept.

Visions of lucrative applications to office and factory automation have fueled the development of a variety of LAN approaches. The inevitable tower of Babel that results from multiple independent approaches to communication has been partially
limited by the development of a set of LAN standards by the Institute of Electrical and Electronic Engineers (IEEE). The IEEE 802 Committee has produced three standards 802.3, 802.4 and 802.5 specifying the physical and data link properties of three competing approaches to the method of controlling a node's access to the LAN.

Ethernet, as specified by IEEE 802.3 (4), achieves access control within the LAN by allowing each node to contend with all the other nodes through a procedure called "carrier sense multiple access with collision detection" (CSMA/CD) that is quite similar to the way participants in a conversation avoid the garbled speech that occurs when more than one person talks at a time; two people may start to talk simultaneously, but usually after a short interval one has gained control of the conversation. This IEEE standard based on Ethernet is the earliest to be published of the three and is widely used in office automation.

The second and third approaches, specified by IEEE 802.4 (5) and 802.5 (6) use a scheme for network access control called a token. This is a brief message passed from node to node in the network. Only when a node has the token can it gain access to the network. This scheme insures that only a single node at a time can transmit information on the LAN and eliminates the possibility of garbled messages. IEEE 802.5 specifies the passage of the token around a physical ring of nodes, and is the network strategy preferred by IBM. IEEE 802.4 transmits the token from node to node in the LAN in a defined but arbitrary order. This *token-bus* approach loses some of the simplicity of the *token-ring* approach, but gains considerable flexibility in the manner in which the network can be laid out. IEEE 802.4 is known as the Manufacturing Automation Protocol (MAP) and has been championed by General Motors. MAP will undoubtedly play a major role in the automation of manufacturing in the future.

Each of the IEEE 802 standards provides an access control means so that multiple
network nodes can share a single wideband transmission medium. Intercomputer communication traffic occurs naturally at high data rates and in bursts that can be organized into short groupings of bits called packets. These characteristics are well suited to a shared channel and to a transmission rate of 1 to 10 megabits per second (Mb/s), characteristics specified by these standards. Commercial equipment is available satisfying IEEE 802.3 that uses either baseband transmission (no carrier frequency) or broadband transmission (multiple carrier frequencies assignments on a cable television-like medium).

LANs have limited geographic coverage (a few kilometers) and computer communication requiring metropolitan, national or global coverage must depend on common-carrier networks. In the developed countries these networks are rapidly converting to integrated-services digital networks (ISDNs) with transmission rates one to two orders of magnitude greater than the present few kilobits per second (kb/s) that is now available over voice grade lines. Present standards include the X.25 packet switching protocol developed by the International Telegraph and Telephone Consultative Committee (CCITT). Much work beyond X.25 remains to be done and CCITT will play a key role as ISDNs are installed throughout the world.

The interconnection of computer networks (including both LANs and ISDNs) will require a standardization effort at a more abstract level than the physical and data link standards developed by IEEE and CCITT. To meet this need the International Standards Organization (ISO) has developed a reference model of network communication as a first step toward the international standardization of various communication protocols. This Open Systems Interconnection (OSI) reference model divides the problem into seven layers covering, for example, the physical aspects in the least abstract first layer and application issues in the most abstract seventh layer. This stratification of concerns has made it possible to organize the various
standardization efforts in an effective manner. For example, different communication protocols in ISO levels 3 through 7 can operate concurrently on a single physical network specified in ISO levels 1 and 2 by IEEE 802.3. Products and standards are now beginning to fall into place and computer networks are, at last, a practical reality.

Data Storage

At the beginning of the electronic computer era in 1946 J. Presper Eckert and John von Neumann recognized that data storage for the ENIAC would have to be arranged in a three level hierarchy (7). Today for personal computers a three-level storage hierarchy is still with us. For mainframe computers the storage hierarchy has grown in complexity to seven levels spanning the range from fast and expensive (semiconductor memory chips) to cheap and slow (optical disks for archival storage). The first level of this hierarchy is directly connected to the CPU while the remaining levels are connected as peripheral IO devices and are generally called secondary or archival storage. The trend toward miniaturization in electronics produced the remarkable advance in memory chip capacity described above, but surprisingly, developments in other storage technologies have kept pace. This is particularly true in secondary storage devices that utilize either magnetic or optical read/write heads to sense and store the patterns of digital information on the storage medium.

Magnetic Storage Technology. To date, magnetic storage devices have been more prevalent than all other technologies combined. For on-line storage, mainframes and minicomputers have used rotating stacks of thin plastic platters coated with a magnetic film. The motion of these disk packs is imparted by the rotation of a central spindle, typically turning at 3600 rpm. Multiple read/write heads move radially to access information stored on concentric circular tracks. These magnetic disks have the advantage of immediate playback, immediate reuse and long term storage. An equally
important quality is reliability, and thus the trend has been away from operator removable disk packs which have proved to be bulky, expensive, fragile and extremely sensitive to environmental contaminants. A controlled environment can be obtained by sealing the spindle, disk pack and the read/write heads into a rugged, encapsulated package. This arrangement prevents the removal of the disk pack and, consequently, is called a fixed disk.

One of the major developments in magnetic storage technology during the last decade has been the introduction of the Winchester disk, a fixed disk with lower cost per bit and higher reliability than its predecessors. This development requires "flying" the read/write heads on a microscopic air cushion over the rotating disk surface. Winchester disks are distinguished by the encapsulation associated with a fixed disk and by the reduced size of the aircushion that is then possible. Disk drive capacities depend on the diameter of the disk and on the number of platters in the stack. Standard diameters are 3.5, 5.25, 8 and 14 inches with capacities today that range from 5 megabytes (Mbytes) to 1 gigabyte (Gbyte) of data. Storage densities have grown since the introduction of the technology and will grow substantially in the future before fundamental limits are reached.

Fixed disks are a useful form of storage for data that must remain available to the CPU (on-line) at all times, but some form of removable storage is needed to provide back-up storage for on-line files and to provide inexpensive storage for little used files. Reel-to-reel, half-inch tape has been the industry standard for removable storage during the past three decades.

Although the capacity and performance of industry standard tape drives have improved by several orders of magnitude over the years, new technology is now challenging their preeminence. Streaming tape, floppy disks, and tape cartridges are
each vying for a share of the removable storage market.

Streaming tape drives substitute microelectronics for the complex mechanical components of industry standard tape drives. Instead of actually starting and stopping the tape to accommodate an uneven flow of data, the streaming tape drive stores incoming data in a buffer memory and adjusts tape speed to match the average data rate. The elimination of mechanical components reduces the cost and greatly reduces the size of these new tape drives.

Thin, flexible mylar disks that rotate in a paper or plastic envelope are properly called diskettes, but are familiarly called floppy disks. In personal computers they are used for both on-line and archival storage. Floppies are slow and have limited capacity, but they are cheap, simple and reliable. There are three standard sizes that agree with the Winchester disk sizes, 3.5, 5.25 and, the almost obsolete, 8 inches in diameter. Unfortunately most personal computer manufacturers write the data on these disks in quite different ways and as a result the capacity of a diskette varies not only with its diameter, but also with the brand. It is rarely possible to read a diskette on one brand of personal computer that had been previously written on another. Diskette capacity varies from 160 kbytes to over 1 Mbyte.

Tape cartridges come in quarter-inch and half-inch sizes and are capable of storing up to 100 Mbytes of data. They share the advantages and disadvantages of industry standard and streaming tape drives: inexpensive media and long access times while the tape moves to the desired position.

Optical Storage Technology. Although magnetic storage has dominated the field for thirty years, a new contender, the optical disk, is moving out of the research and development laboratories into the marketplace. The technology used for compact disk (CD) audio recording is now available for storing digital information. These disks have
a 600 Mbytes capacity, are inexpensive and very compact. Information can be read
from, but not written to these optical disks and as a result they are called CDROMs. A
more expensive variation of optical disk technology is now being introduced which
partially removes this limitation by making it possible to "write-once and read-many"
times. Both CDROM and WORM optical disks have data transfer rates about an order
of magnitude lower than Winchester disks, but the low media cost and the high
capacity of the optical technology makes it a very attractive alternative where
information storage is not volatile. For example, WORM technology can be used for
archiving medical records or radiological images where an audit trail or a permanent
record is desirable. Optical disks are likely to revolutionize many aspects of education
because of their vast capacity, their low cost and their ability to store images as well as
text, an ideal combination for interactive teaching. One application of the technology
now available is a CDROM published collection of the latest information on the
diagnosis and treatment of certain rare cancers.

User Amenities

The basic technologies described above provide the physical aspects of a modern
computer system, but without software and special IO devices to interface the system
to the user it is hardly more useful than ENIAC. Without this user interface few people
can deal with the unforgiving and hostile nature of a bare computer system. Even
those who deal directly with a computer on its own terms (endless strings of one and
zeroes) find their productivity and capacity to accomplish their goals is markedly
curtailed.

Over the last three decades scores of computer languages, operating systems,
integrated environments and IO devices have been developed to bridge the gap between
the computer and its user. There is, however, still a long way to go before a large
fraction of the public will find dealing directly with a computer tolerable, let alone pleasant and helpful. Below we review some of the steps that have been taken so far.

**Computer Software.** Computer programs, lists of step-by-step instructions to be interpreted by the computer, are today usually written in languages convenient for the programmer. These *high-level languages* are subsequently translated by another computer program into the machine's language. High-level languages are not like English, but have a very restricted syntax that can be interpreted unambiguously by the translation program and, if correctly written, unfailingly yield the proper machine language. Good high-level languages simplify the task of the programmer by handling all routine housekeeping jobs, by producing a resulting program that is readable, and by producing a portable program, one that can easily be transferred to a computer of another type. Programming languages are usually partitioned into procedural languages and declarative languages. Procedural languages have been known for three decades and specify the computer's sequence of actions much like a recipe specifies a cook's actions.

Most of the better known languages fall into this class: BASIC (8), COBOL (9), PASCAL (10), FORTRAN (11), FORTH (12) and LISP (13). These languages are designed to run on classical von Neumann machines and to deal with administrative, engineering and numerical tasks.

The most widely adopted declarative language is PROLOG (14), a language designed for manipulating logic statements. In contrast to a procedural language, PROLOG allows the computer to achieve the result specified by a logic statement without the need for the user to specify the means. Developed in England and now widely in use in the U.S. academic community, PROLOG has been most enthusiastically accepted in Japan where it is the primary language of their government supported
effort to develop fifth generation technology (15).

Programs used for the translation of source code (the high-level language produced by the programmer) into machine language are of two kinds: interpreters and compilers. Interpreters translate each line of source code anew for each execution of the program whereas a compiler translates the source code only once producing object code in machine language form that can subsequently be reused without repeated translation for each execution of the program. The object code produced by compilers can be highly optimized for a specific machine and will execute much faster than the same program executing through an interpreter. On the other hand interpreters often have many more amenities than compilers, making the former easier to use since the programmer's work can be tested as the program is written. Some modern compilers have many of the advantages of interpreters, so that languages like PASCAL, although compiled, can be as convenient to use as the popular beginner's BASIC interpreter.

The huge market for personal computers has spawned a new set of programming tools called fourth generation languages. These languages operate at the command level used in various popular program packages. Because of the potential for high volume sales many software vendors have invested enormous effort in the amenities for these packages. For example Visicalc, probably the bestselling software product in the world, allows the user to prepare a spreadsheet made up of rows and columns of interdependent figures in a way that agrees so well with intuition that a beginner can often master it without lessons or a detailed instruction book.

The control and allocation of the various resources available to a computer system is the responsibility of the computer's operating system. This complex set of programs manages the allocation of the computer's memory, assigns CPU cycles to processes ready for execution, and controls IO activity on the computer's bus. The operating
system makes it possible for the user's programs (usually called application programs) to communicate with various peripheral devices, with secondary storage devices and with other computers by means of a computer network. A good operating system will provide the programmer with a consistent and simple interface to the system. An excellent operating system will provide such superior services to the application programmer that the user's view of application programs will also be consistent and simple.

Operating systems may be proprietary (produced by a single manufacturer) and may be restricted to one machine family. A recent trend, particularly for minicomputers and personal computers, is the increasing popularity of operating systems, such as UNIX, MSDOS and UCSD-p System, that have been ported to many different computer systems. The portability of an application program is markedly enhanced if it can run under one of these popular operating systems.

Program packages such as Visicalc are often superimposed on an operating system, forming a kind of super operating system or integrated environment for the user that leads to an improved and consistent user interface. On many personal computers today these packages can produce a simulation of a desktop environment in which the equivalent of multiple pieces of paper and multiple folders (or files) of data are presented on the computer video display. The ability to switch rapidly from one piece of paper at the top of the desk top stack to another through the manipulation of windows on the video display is a significant characteristic of these packages.

A very important part of an integrated environment is file handling ability. The storage technology described in the previous section must be tamed by the operating system allowing the user to easily open a file no matter where it is stored; read, search or modify the file; and finally close the file and return it to the proper place in storage.
The power of an integrated environment with good file handling can be appreciated when one realizes that a file may contain source code, a chapter of a book, this manuscript, a portion of a digitized electrocardiogram, object code or anything that can be represented by a finite string on alphanumerical characters. Unfortunately, different operating systems and thus different integrated environments have different conventions for storing files. They are compatible with each other only with the aid of special translation programs. Hence the trend away from single-computer operating systems.

Input Output Devices. Since 1946 IO devices have come a long way toward doing their part in providing the needed user amenities. Originally ENIAC was programmed by rearranging wires on a plug board. Later punch cards were imported from the world of business machines where they had been in use for more than 60 years. Invented by Hollerith for the processing of data from the 1890 U.S. census (16), they had matured over the years at the hands of IBM. The introduction of the cathode ray tube as a computer output device in the early 1950s led to today’s video displays. The forerunner of the personal computer was developed by Clark and Molnar in 1962 (17). Its IO devices were similar to the keyboard, floppy disk and video display found on most of today’s personal computers. None of these are really well suited to the job. The keyboard requires a skill not possessed by all and made more difficult to acquire by the QWERTY layout developed a century ago to avoid mechanical tangles of the keys. The floppy disk has slow transfer rates and limited storage capacity. The video display is not as convenient to read as hard copy, is tiring for the neck and back and usually limited to alphanumerical text.

New input devices have become popular largely as a result of the small fraction of personal computer users who find the keyboard easy to use. A pointing device such as a mouse or a trackball allow the user, with one smooth motion of the hand, to pick out
for attention a character or a small region of the video display screen. A touch sensitive screen is a form of pointing device that has been in use for over a decade and has been particularly popular in medical applications.

Video displays have improved with the introduction of buffer memories that store a single bit for every picture element (pixel) displayed on the screen. These displays are called *bit-mapped* displays and they allow a major improvement in the display flexibility over the previous character oriented displays. Graphics and windows are two of the results of this technology and they are demonstrated admirably in the Macintosh, Amiga and 520ST personal computers.

Computer output in hardcopy form is produced most often by printers although plotters are used for high quality graphic output. Printers fall into three categories that are roughly correlated with price: draft, letter and publication quality. Draft printers are the least expensive and use some form of dot matrix to form the printed symbols. The most popular scheme is a matrix of tiny pins that strike a typewriter ribbon when actuated by an electromechanical transducer. A newer and quieter scheme is a matrix of tiny ink jets that are mounted in a replaceable cartridge. Some of these matrix printers approach the quality of a good typewriter, that is letter quality, and some produce quite adequate graphics. Letter quality printers use the impact of type wheel or ball against a ribbon to produce printed symbols similar in all respects to those produced by an office typewriter. The newest and most expensive of the three categories is the laser printer which uses xerographic techniques to produce printed symbols of a quality normally associated only with typeset copy suitable for publication. With adequate software and image memory a laser printer can also produce very high quality graphics.
Future Trends

The division between a description of state-of-the-art technology and a prediction of future trends is somewhat arbitrary, particularly for those developments that are now in the laboratory or are just beginning to appear in the marketplace. We have chosen to include here those technological developments for which there is considerable growth potential. Thus, although there are some products already on the market in speech recognition, voice synthesis, expert systems, computational imaging and scientific workstations, we expect these areas to have enormous future potential for medicine in general and for cardiology in particular.

Basic Technologies

Trends in the four basic technologies outlined above will continue. Microelectronics will move to higher densities and larger chip sizes. Instead of doubling chip complexities every year as was the case from 1960 to 1975, the semiconductor industry is on a course that will double chip complexity only every two years (18). Already four million-bit memories are being developed in the laboratory and several more doublings in complexity beyond that achievement can be expected before fundamental physical limits are encountered. By the end of the century integrated-circuit devices with 100 million transistors should be on the market. This could mean lap top computers with the power of today’s supercomputers and semiconductor memories with the capacity of today’s hard disks.

Computer networks will slowly move to glass fibers as electro-optical technology matures. Fibers are fundamentally superior to copper cables because they are cheaper, have capacity for data rates higher by several orders of magnitude, are insensitive to electromagnetic interference, are more secure and take up less space. Problems at the interface between electronic systems and optical fibers will give coaxial cable
technology a number of years of useful life before it is displaced by fiber. Data rates on LANs will grow faster than on common-carrier networks. LANs with the ability to transmit pictures will become commonplace within this decade as a result of the driving force of electronic radiology (19). Although the telephone companies are installing glass fibers throughout their systems it will take many years to convert the entire telephone plant. Connections to subscribers offices and homes will be installed only after connections between central offices have been completed. In summary, more digital communication at lower cost is on the way. Standardization will lead to more and cheaper network products so that computer networks will become a fundamental part of all computing.

The major trend in secondary storage will be toward the incorporation of more microelectronics so that the physical devices themselves can be simpler, cheaper and more reliable and so that the host computer system can deal with a hierarchy of storage devices in a more uniform manner. Storage densities will continue to increase for both magnetic and optical technologies. We estimate that the contenders in the hierarchy will be: optical ROM disks, magnetic tape, optical WORM disks, erasable optical disks, Winchester cartridge disks, Winchester fixed disks and semiconductor chips. The order of these seven contenders is from the cheapest to the most expensive per bit of storage. For the most part, this also orders the contenders from the slowest to the fastest access time.

Beyond the major developments discussed in the next sections, we see two other trends in the amenities: integrated environments and desk top publishing. The trend will continue toward the integration of the programming language, communication and database environments into one uniform interface with the user. These changes will be driven by the PC marketplace, but will be likely to be based on developments in academic computing. Graphics, icons and even pictures will be featured so that ease of
use will be promoted by intuitive rather than rote understanding of the operation of the system.

The inexpensive laser printer will trigger an abundance of software development for the new field of desk top publishing. Publication quality copy can now be produced by the combination of a personal computer and a laser printer and this fact will generate an entirely new market segment. Physical paste-up will be replaced by soft-copy paste-up on a personal computer's video display. Databases integrated with the desk top composition system will store the raw copy including graphics and halftones ready for paste-up. These developments in desk top publishing along with those in networks will undoubtedly have profound implications for the preparation and publication of scientific results. It is not clear what the eventual effect on traditional journals will be, but some editors will soon begin accepting camera-ready copy in electronic form that includes graphics and halftones.

Speech Recognition and Voice Synthesis

The understanding of continuous speech by computer is still a distant goal, particularly if the speech is produced by a wide variety of talkers. Until the end of the century progress toward this goal is likely to be slow and steady, without obvious scientific breakthroughs. On the other hand, isolated word recognition for limited vocabularies is here today. Several research laboratories have phone numbers that will connect anyone wishing to call with a computer having the capability to identify, with accuracies exceeding 90%, any of the spoken digits from zero through nine. There are, in fact, inexpensive peripheral devices for personal computers that allow the user to train a computer to recognize a few hundred isolated words spoken by a single talker. Uses in the cardiac catheterization laboratory and in over-reading electrocardiograms seem likely.
Voice output from computers is familiar to anyone who has called for operator assistance with an unknown telephone number. There are two basic methods of voice output which may be distinguished by the naturalness of the result. The more natural voice-output method uses recorded or hand-edited human speech elements stored in compressed form. The more compression used in storing the speech the less natural it sounds when reproduced. The second method of voice output synthesizes the speech from either a sequence of phonemes or from a natural language text file. This method allows a vocabulary of unlimited size, is more flexible and uses less computer storage, but results in speech that is rather unpleasant. Some personal computers now have the ability to produce a synthesized vocal version of text files. At least one personal computer can store and reproduce a small amount of natural speech. A talking self-test system for diabetics has recently been offered commercially (20). The potential for communicating with computers through speech is exciting and will surely expand greatly in the years to come.

Artificial Intelligence and Expert Systems

Since the phrase was coined by John McCarthy in 1956, Artificial Intelligence or AI as it is frequently called, has been the center of excitement and controversy. Winston (21) defines AI as "the study of ideas that enable computers to be intelligent." A more cynical view is that AI is defined by what the people in the field do. The leaders of the field see the rapid deployment of AI techniques to medicine, business, manufacturing and education (15). Detractors say that "Artificial Intelligence has failed to live up to its promise and there is no evidence that it ever will" (22). The truth lies between the extremes, as usual. There are many accomplishments today of practical value, but fundamental problems remain. To be listed among such accomplishments are logic programming (23), (in languages such as PROLOG), programs that solve mathematical problems symbolically (24) database query languages with capabilities for deduction
(25), and expert systems (15). A fundamental problem that we see is the absence of diversity in AI systems; diversity of the kind that makes living systems resilient and when restricted leads to fragility. A second fundamental problem is the inability of AI systems to explain their actions. Some early results have been achieved in explainable systems (26), but much work remains to be done before a robust solution to this problem is obtained.

Expert systems are computer programs that solve problems by employing reasoning tasks based on the encoded knowledge of human experts coupled with the deductive capability of a powerful inference engine. This inference engine may be realized by incorporating the rules of logic in a computer program or by building a special processor well-suited to logical reasoning.

In applications where the domain of knowledge is circumscribed, such as locating cable faults in a telephone plant, expert systems have demonstrated practical usefulness. Work continues on programs to carry out medical diagnosis (27), but the ability to explain results fully, remains elusive. Nevertheless, expert systems are likely to appear in many cardiology settings (28, 29, 30).

Computational Imaging and the Scientist’s Workstation

Computational imaging is the union of the three fields of image processing, computer vision and computer graphics. Previously separate, these three fields are now merging their technical capabilities. They now each use raster graphic displays and, furthermore, microelectronic devices will soon be available that will allow the integration of special computational and IO requirements from each of the fields into a single inexpensive system. For years ultrasonic echocardiography has been used to image the beating heart and computed tomography and magnetic resonance imaging have recently been applied to this same task. Results of all three imaging modalities
are certain to improve in the next few years. Thus, it seems reasonable to predict that computational imaging will become of increasing importance to the cardiological investigator and diagnostician.

This view may seem farfetched because of the present cost of computational imaging systems, but consider the following trend. In 1970 a handful of integrated circuit memory chips could store enough characters to fill a video display screen. The era of the ubiquitous alphanumeric computer terminal began. In 1980 a handful of memory chips could store enough graphic information to fill a screen. The era of the personal computer began. By 1990 a handful of chips should be able to store a high quality image of the heart. Disk transfer rates should be fast enough to give the illusion of smooth movement of the image. If systems that produce such images are as plentiful as today's personal computers, what are the implications for clinical practice and research?

This leads us to our last topic, the scientist's workstation. It differs from personal computers in several ways (31). First, a workstation is fundamentally part of a computer network. It depends on the network for information and for certain resources that are not needed locally. Second, the workstation may be thought of as a well-thought-out kit of information handling tools. Finally, the workstation will be capable of smoothly managing large files and databases, even ones that exceed the capacity of local secondary storage. The personal computer was a step along the way and the scientist's workstation is a significant additional step.

Both diagnosis and research depend heavily on pictures; in addition to the imaging modalities mentioned above, electrocardiograms, chest films, angiographs, tissue sections, nuclear medicine images and many more can be listed. The use of computers in cardiology has been handicapped by the absence of a readily available capability to
present, analyze and quantify images. We believe that, for computers in cardiology, the most important trend in information technology is the evolution of a high-performance workstation for cardiologists, one capable of presenting high quality pictures, analyzing these images and quantifying the results.
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### Table 1

<table>
<thead>
<tr>
<th>Generation</th>
<th>First</th>
<th>Second</th>
<th>Third</th>
<th>Fourth</th>
<th>Fifth</th>
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<tr>
<td>Years</td>
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<td>1957-63</td>
<td>1964-81</td>
<td>1982-89</td>
<td>1990-</td>
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<td><strong>Example Computers</strong></td>
<td>Eniac</td>
<td>NCR 501</td>
<td>IBM 360, 370</td>
<td>Cray XMP</td>
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<td></td>
<td>Edvac</td>
<td>IBM 7094</td>
<td>PDP-11</td>
<td>IBM 308</td>
<td>Merging of telecommunications and computer technologies</td>
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<td></td>
<td>Univac</td>
<td>CDC-6600</td>
<td>Spectra-70</td>
<td>Honeywell 200</td>
<td>Extensive modularity</td>
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<td>IBM 650</td>
<td>Cray 1</td>
<td>Cray 1</td>
<td>Amdahl 580</td>
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<td><strong>Telecommunications technology</strong></td>
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<td>Digital transmission</td>
<td>Satellite communications</td>
<td>Integrated systems digital network (ISDN)</td>
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<td></td>
<td>Teletype</td>
<td>Pulse-code modulation</td>
<td>Microwaves</td>
<td>Optical fibers</td>
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<td></td>
<td></td>
<td>Networking</td>
<td>Packet switching</td>
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<td><strong>Computer hardware</strong></td>
<td>Vacuum tubes</td>
<td>Transistors</td>
<td>ICs</td>
<td>Distributed computing systems</td>
<td>Advanced packaging and interconnection techniques</td>
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<td></td>
<td>Magnetic drum</td>
<td>Magnetic-core memories</td>
<td>Semiconductor memories</td>
<td>VLSI</td>
<td>Ultralarge-scale integration</td>
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<td>Cathode-ray tube</td>
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<td>Magnetic disks</td>
<td>Optical disks</td>
<td>Parallel architectures</td>
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<td>Minicomputers</td>
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<td>3-D Integrated-circuit design</td>
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<td><strong>Computer software</strong></td>
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<td>High-level languages</td>
<td>Very high-level languages</td>
<td>Ada</td>
<td>Gallium arsenide semiconductor technology</td>
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<td>Machine code</td>
<td>COBOL</td>
<td>Structured programming</td>
<td>Widespread packaged programs</td>
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<td></td>
<td>Autocode</td>
<td>ALGOL</td>
<td>Timesharing</td>
<td>Expert systems</td>
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<td></td>
<td></td>
<td>FORTRAN</td>
<td>LISP</td>
<td>Object-oriented</td>
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<td>PROLOG</td>
<td>languages</td>
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<td>2-kilobyte memory</td>
<td>32-kilobyte memory</td>
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<td>16-megabyte memory</td>
<td>Concurrent languages</td>
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<tr>
<td></td>
<td>10 kiloinstructions per second</td>
<td>200 kIPS</td>
<td>5 megainstructions per second</td>
<td>30 MIPS</td>
<td>Functional programming</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Symbolic processing (natural languages, vision, speech recognition, planning)</td>
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</table>

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Glossary

The field of information technology is suffused with acronyms and abbreviations. So many new concepts requiring unambiguous technical names have been introduced that these compact forms have become an important part of the vocabulary of information technology. Below the compact and expanded forms are listed together. Generally, in the accompanying text the compact form is used, in accordance with usual practice in computer technology.

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>AI</td>
<td>Artificial Intelligence</td>
</tr>
<tr>
<td>ALU</td>
<td>Arithmetic-Logic Unit</td>
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<tr>
<td>CCIT</td>
<td>International Telegraph and Telephone Consultative Committee</td>
</tr>
<tr>
<td>CDROM</td>
<td>Compact-Disk Read-Only Memory</td>
</tr>
<tr>
<td>CPU</td>
<td>Central Processing Unit</td>
</tr>
<tr>
<td>CSMA/CD</td>
<td>Carrier Sense Multiple Access with Collision Detection</td>
</tr>
<tr>
<td>ENIAC</td>
<td>Electronic Numerical Integrator And Calculator</td>
</tr>
<tr>
<td>IC</td>
<td>Integrated Circuit</td>
</tr>
<tr>
<td>IEEE</td>
<td>Institute of Electrical and Electronics Engineers</td>
</tr>
<tr>
<td>IO</td>
<td>Input-Output</td>
</tr>
<tr>
<td>ISDN</td>
<td>Integrated Services Digital Network</td>
</tr>
<tr>
<td>ISO</td>
<td>International Standards Organization</td>
</tr>
<tr>
<td>LAN</td>
<td>Local Area Network</td>
</tr>
<tr>
<td>LINC</td>
<td>Laboratory INstrument Computer</td>
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<tr>
<td>MAP</td>
<td>Manufacturing Automation Protocol</td>
</tr>
<tr>
<td>MOS</td>
<td>Metal Oxide Semiconductor</td>
</tr>
<tr>
<td>OSI</td>
<td>Open System Interconnection</td>
</tr>
<tr>
<td>RAM</td>
<td>Random Access Memory</td>
</tr>
<tr>
<td>ROM</td>
<td>Read-Only Memory</td>
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<tr>
<td>VLSI</td>
<td>Very Large Scale Integration</td>
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<tr>
<td>WORM</td>
<td>Write-Once Read-Many times</td>
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