The First Decade of Personal Computers

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Invited Paper

The first decade of personal computers is characterized by three generations of these man-made devices. During the last six years alone, the number of personal computers purchased has increased by two orders of magnitude. This rapid growth has been catalyzed by innovations in computing and communication technology and by the advent of systems with friendlier human–machine interfaces geared towards individual needs. As the microelectronics revolution progresses and better software methodologies evolve, the personal computer will find widespread use in nontraditional application areas involving computing operations on information of many different types. This paper discusses the key features of contemporary personal computers. Four different market niches are delineated and their characteristics analyzed.

I. Introduction

Background

Since the dawn of the electronic computer era in the 1940s, there has been a sustained endeavor to minimize the human effort involved in communicating with the computer. The advent of higher level programming languages in the 1950s and the concepts of time sharing in the 1960s serve as evidence of this hypothesis. As computer logic and memory costs continued to decline by more than 20 percent every year, many corporations and individuals perceived that it was feasible to manufacture computers that were within the purchasing power of individuals. In 1968, Hewlett-Packard introduced the HP 9100A which was a hybrid between a calculator and a computer and was aptly described as a "computing calculator" [1]. Subsequently, in early 1973, Xerox designed the Alto personal computer "as an experiment to study how a small, low-cost machine could be used to replace facilities then provided only by much larger shared systems" [2]. The HP 9100A was geared primarily towards the computing needs of scientists and engineers. The Alto, too, was used more by persons with prior knowledge of computing techniques. The major thrust towards "personalization of computing" was provided by the widespread use of the microprocessor in the early 1970s. Microprocessors enabled personal computers to be built at lower costs than ever before.

Definition

Personal computers, like minicomputers, have no rigid definition. Today the term "personal computer" usually connotes a computer fulfilling *all* the following characteristics [4], [5]:

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a) The price for the complete system is within the reach of individual buyers (usually under $5000).
b) The computing power is provided by using contemporary microprocessor technology.
c) The system is distributed through mass-marketing channels, with emphasis on sales to people with little or no prior experience with computers.
d) The system is flexible enough to accept a wide range of programs serving varied applications in industry, business, and at home; it is not designed for a single purpose or a single category of purchasers.
e) The operating system facilitates an interactive dialogue.
f) The computer can handle at least one high-level language, such as Basic, Fortran, or Cobol.

In short, a personal computer is a stand-alone microprocessor-based, low-priced interactive system. The credit for designing the first personal computer [1], [3]–[5] is usually given to Micro Instrumentation and Telemetry Systems (MITS) Inc. for its Altair 8800 system designed during 1974 and advertized on the cover of the January 1975 issue of *Popular Electronics*. The basic system sold for $395 in kit form and $621 in assembled form. The Altair 8800 Advanced Accounting/Engineering System included sophisticated features and sold commercially for $10 500. The Altair 8800 is no longer manufactured. The next two years (1976–1977) witnessed the entry of Radio Shack, Apple, and Commodore into the market. The success of these companies convinced mainframe giants such as IBM and minicomputer leaders such as DEC to enter the fray. Unlike the Altair 8800, which was intended mainly for hobbyists, these larger companies emphasized fully assembled turn-key systems that were more user friendly. Intense competition has led to plummeting prices and increased performance at a hectic pace.

In terms of both hardware and software, mainframe computers were the harbingers of personal computers. The successive stages of the microelectronic revolution involving the inventions of vacuum tubes, transistors, integrated circuits, and large-scale integrated circuits have all contributed to the evolution of sophisticated computer hardware that permits large computing power to be generated in tiny wafers of silicon, and at minimal costs. Relative to hardware capabilities, the emergence of the personal computer is even more dependent on the development of better and more human-oriented program interfaces and methodologies. The historical trends are summarized in Table 1. Today's personal computers are equivalent in basic computing power to the mainframes of the 1960s and the minicomputers of the 1970s. However, unlike the 1960s and the 1970s when computers were principally used for well-struc-

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Table 1 Five Generations of Systems

	Hardware		Software		
Generation	Technology	Example Systems	Methodology	Examples	Principal Kind of Data Handled
1st Generation 1950's	vacuum tubes	ENIAC, WHIRLWIND	binary	0, 1 (machine specific)	binary numbers
2nd Generation Early 1960's	transistors	IBM 709	Assembly	Assembly (machine specific)	numbers
3rd Generation Late 1960's	integrated circuits	PDP 11	higher-level languages	Fortran, Pascal, PL/I	numbers and some text
4th Generation 1970's	large scale integration	IBM 370; AMDAHL 470	elementary information systems	IMS, SQL	numbers, text
5th Generation Mid-1980's	hardware implementation of traditional software functions, truly user-friendly systems	yet to come	high level decision support systems	yet to come	numbers, text, video

tured jobs such as scientific calculations or payroll accounting, today's personal computers are primarily used for *ad hoc* analyses and for supporting the solution of nonstructured tasks.

At the heart of any personal computer there is a silicon-chip microprocessor capable of performing hundreds of thousands of calculations every second, complemented by memory chips that provide the primary storage for instructions and data. External storage devices, such as cassette tapes or floppy disks, augment the memory capacity and provide a storage medium that can be physically transferred from one personal computer to another. Input is through a typewriter-like keyboard unit. Output can be in the form of printed paper; this requires attachment of a printer unit. More frequently, the output is displayed either on a normal television screen or on a specialized CRT screen called a monitor. Attachment of a modem (for modulator/demodulator) permits the computer to receive and transmit data over a conventional telephone line. The current trend is to share information stored on different systems by linking multiple personal computers in a network. In addition to the hardware components described so far, any personal computer requires software, especially an efficient operating system, which is comprised of a set of programs that manage the computer's resources, supervise the storage of programs and other information, and coordinate various tasks. Finally, there are application programs to carry out specific functions at the direction of the user.

Markets

Over the years, the use of personal computers has nucleated around four primary areas: in business, in science and engineering, at home, and in education. Business use is primarily structured around spreadsheets, word-processing, elementary graphics, database, and communications for hookup to host computers and local area networks. The applications are somewhat similar in the scientific area. In addition, the personal computer is utilized for high-quality graphics, for communicating with scientific instruments and equipment, and for on-line analysis of data. At home, the personal computer is primarily used for entertainment purposes. Many personal computers are now finding their way into the home primarily to allow users to accomplish job-related tasks. This is consistent with the observed fact that tasks that require sustained work, attention, or reflection are usually done by managers at home [7]. In the education sector, personal computers are being used for classroom instruction, one-to-one tutorials, and self-paced Computer-Based Training (CBT). Personal computers are fast taking over the role served by the calculator—in fact, several universities require entering students to either own or acquire a personal computer [6].

The analogy with calculators can be considered at another level. In recent years the prices of calculators have stabilized while the simple four-function calculator has almost disappeared. Even the low-priced calculator contains 15–20 functions and as technology improves more functionality in terms of timekeeping and games is being inserted. In the case of personal computers, prices for a full business system are expected to stabilize at around $1500 with increasing functionality over time. In order to predict specific areas of enhanced sophistication, it is necessary to study the different building blocks that constitute a personal computer.

II. Hardware

A personal computer consists of three different classes of hardware subsystems—the central processing unit (CPU), the memory subsystem, and the input–output subsystem. Trends in each of these three areas are described below.

Central Processing Unit (CPU)

The CPU of a personal computer consists of one or more microprocessors. Two parameters upon which to gauge the computing power of a microprocessor are its word size and the frequency of its clock [10]. The word size reflects the basic unit of work. A larger word size implies more information can be processed in parallel; also, it enables access to a larger volume of memory. The first microprocessor, the Intel 4004, was only 4 bits wide. In their twelve years of existence (1971–1983) microprocessors have witnessed four generations characterized by different word sizes (see Table 2). Increased word size is made possible by implanting larger numbers of electronic elements on the same chip. This number has increased from 2300 in 1971 to 450 000 today. During this period, the clock frequency has increased by more than an order of magnitude. The first generation of personal computers used 8-bit microprocessors. Personal computers using 16-bit microprocessors were first introduced in 1981 [8]. The first use of a VLSI 32-bit microprocessor was in the Hewlett-Packard 9000 series of com-

Table 2 Microprocessor Characteristics

	4-bit	8-bit	16-bit	32-bit	64-bit (projected)
Year of First Chip	1971	1972	1974	1981	1986
Number of Devices	2300	10 000	70 000	450 000	1 000 000
Function	calculator	dedicated controller	minicomputer	micro-mainframe	maximicro-mainframes
Clock Speed (in MHz)	0.4	0.5	1	10	50
Prices (1984)	$1	$5	$50	$250	$1250

puters, which are currently too expensive to be classified as personal computers [9]. Around 1985, the 32-bit microprocessor will become the industry standard. Just as the mainframe computer industry has continued to use the 32-bit word size for the last two decades, it is expected that 32-bit microprocessors will become the most popular word size, at least until the end of the 1980s [23]. Meanwhile, there is a growing trend to use more than one microprocessor within the same personal computer either for supporting multiple operating systems or for performing dedicated functions such as keyboard decoding, disk control, or graphics subsystems.

Around the time of the introduction of the first personal computer, Moore had predicted that by the end of the decade the complexity of VLSI chips would double every two years [12]. One advantage of the increased device density has been the ability to implement larger and more powerful instruction repertoires enabling more compact programs. Single instructions now perform multiple functions. Also, contemporary instructions have a close resemblance to instructions of higher level languages thus facilitating compilation of such programs by performing, in hardware, an increasing number of functions traditionally done in software. In recent years, the focus has been on supporting instruction sets with an established base. The DEC F-11 microprocessor uses the PDP-11/34 instruction set, and the Data General microEclipse uses the DG-Eclipse instruction set; these chips have been used in the personal computers developed by these companies [13], [14]. IBM, on the other hand, has chosen to microcode Motorola 68000s to emulate its 360/370 instruction set; these microcoded chips are used in the IBM PC-XT/370. Such personal computers with direct software compatibility with popular mainframes and minicomputers can be used to off-load applications from a larger system and to run them in a local environment. Additionally, executives can be provided with personal computers that have greater potential of using existing software for accessing databases maintained on the central system. In coming years personal computers will offer greater flexibility in retrieving information from computers of widely different architectures and integrating such information in a cohesive manner.

Primary Storage

Primary memory is of two kinds: read-only memory (ROM) and random-access memory (RAM). In the former, information is "written in" at the factory and cannot be altered subsequently. Most manufacturers supply system programs on ROMs because such programs are secure against power failures, and users are less able to duplicate programs in this form. RAMs offer both read and write capability and are used for general program/data storage. RAMs are of two types—dynamic RAMs which are cheaper but need to be "refreshed" very often, and static RAMs which are less dense and costlier but need no refresh. Dynamic RAMs have higher bit densities per chip and are the device of choice for most personal computer program/data primary memory.

The size of memory refers to the amount of RAM installed in the personal computer. The upper limit is determined by two constraints. First, the maximum limit from a logical viewpoint is dependent on the memory address space of the particular microprocessor used in the personal computer. Most 8-bit microprocessor-based personal computers can deal with programs that are no larger than 64K bytes in size (16-bit address space). Most 16-bit personal computers offer native address space of 1 Mbyte or more (20-bit or greater address space). The second constraint comes from physical packaging limitations, especially in the case of portable computers [15]. Using the popular 64K-bit RAM chip, a 1-Mbyte (or 8-Mbit) memory space implies a minimum of 128 chips, taking up substantial room inside the personal computer. For this reason, current personal computers rarely offer more than 4 Mbytes of memory capacity within the system unit. With the introduction of the 256K-bit RAM, these packaging constraints will now shift by a factor of four and by a further factor of four around the end of the 1980s when the megabit chip becomes popular. The speed of memory devices doubles every two to three years. Over the past decade, memory density increased by a factor of 64 with a simultaneous reduction in costs, on a per-bit basis, by a factor of 25. This trend should continue for several more years.

Secondary Storage

Secondary storage devices offer larger and relatively inexpensive (though slower) memory for long-term storage of programs and data files and a mechanism, via removable media, for physical transportation of programs and data from one system to another. The *cassette tape*, though inexpensive and widely supported on all systems, is unsuitable for serious applications because of its low speed, sequential access, and low reliability. Currently, the most popular personal computer secondary storage device is a *floppy disk* consisting of a disk of mylar with a coating of magnetic material on one or both sides. Data are stored on concentric magnetized tracks on the disk surface. Heads for reading or writing data are moved radially across the disk to access a specified segment of circular track. The storage capacity varies greatly depending on the formats used for the stored data, the quality of the surface media, and the head design. Formatting considerations include: the density of data stored along the tracks (bits per inch), the number and density of concentric tracks stored on the medium (tpi), the number of segments into which each track is subdivided into for addressing purposes, and the software and hardware conventions used for interfacing with the disk. Floppy disks currently have capacities of between 125K bytes to 3 Mbytes. Floppy disks have standardized around two principal physical formats: one is the 5-1/4 in which is the current *de facto* industry standard drive, and the other is the 8-in drive which is less popular and is not available on many current generation personal computers. New physical standards in small-sized floppy disks are also evolving. However, floppy disks from one personal computer vendor do not generally run in the disk drive of another vendor because of different data-formatting conventions. For most business applications, two drives are necessary since many software application programs (e.g., language compilers, spreadsheets, etc.) make use of two drives. With a one-drive system, even simple operations such as backup, compiling, and editing require multiple disk swappings. Frequently, two read/write heads are ganged together, one to access the top surface of the floppy disk and the other to access the bottom surface. Although only one head is active electronically at any one time, such a double-sided floppy unit doubles the amount of storage capacity and, as such, is preferred over a single-sided drive. Technological advances have enabled manufacturers to double the density of recorded information by doubling the number of tracks per inch. This has led to a new generation of double-density floppy units. Double-density, double-sided recording has become industry standard, yielding floppy capacities of 320K–1 Mbytes in the case of 5-1/4-in disks.

The primary performance characteristic of floppy disks is the response time to a read/write request which may range from 200 to 500 ms. For a single file request, this may not be a significant amount of time; however, during language compilation or word processing, an individual user command may involve twenty or more accesses to the floppy disks, and disk accesses may account for more than 80–90 percent of the total command execution time. Where better performance is required, a hard disk is used with access times ten times as fast as the floppy disk.

The *Winchester disk* was originally projected to contain 30 Mbytes and two disk units were ganged together. Consequently, the total capacity was 30/30 and hence the name Winchester, based on the Winchester rifle of the old West. A Winchester is a rigid disk with a moveable read/write head in a sealed module. The disk is not removable. Because it is in a sealed unit, the introduction of dirt and impurities from the external environment can be controlled more rigorously; consequently, the read/write heads can fly at heights that are orders of magnitude closer to the disk surface than in the case of a floppy read/write head. This enables higher density of recording and faster speeds of access. The rigid Winchester disk is rotated about ten times faster than a floppy. Typically, a Winchester disk unit costs between $1500 and $2500 whereas a 5-1/4-in floppy unit costs between $300 and $500. Further, Winchester disks are very sensitive to dirt and foreign substances since the low-flying disk head cannot tolerate small particles of smoke and pollen. Also, the Winchester cannot be taken out and put on the shelf like a floppy. Consequently, there is no backup copy of the data stored on the Winchester. Normal backup involves the use of many floppy disks or a "streaming tape," which is a cassette tape containing an image of the information stored on the entire Winchester disk.

A promising technology that will greatly impact the secondary storage capacities of personal computer systems is the *optical disk*. Optical disks have their roots in the laser video-disk technology with modifications and interfaces designed especially for processing digital data in a personal computer environment. Several manufacturers including DEC, Toshiba, IBM, Thomson/CSF, Phillips, and Sharp will be releasing such devices in the 1984–1985 timeframe. The advances represented by this device are large storage capacity per disk (approximately 200 Mbytes in a 5-1/4-in format) and low cost per bit ($25–$50 per 5-1/4-in optical-disk cartridge). The disks themselves are reliable, easily transportable, and not subject to as delicate handling constraints as magnetic media. Binary patterns of 1 and 0 are written on the disk using a laser and are read back from the disk by the same laser device at a lower intensity level. The first generation of optical disk units will allow information to be written once only. Access times will be a factor of 3–4 times faster than floppy speeds. The limitation of nonerasability implies that whenever a modified version of one's data is to be recorded, it must be written in a new area of the disk and the old copy marked as being not-the-current one. Such an archival storage procedure is desirable for many applications, for instance, financial records, medical records, tax returns, and other applications where an audit trail is desirable. Optical disks are likely to be most suited for two distinct sets of applications. First, as a permanent storage media for financial, educational, medical, and legal records. Second, as a low-cost media for widespread distribution of databases containing information that is updated regularly, e.g., for distributing product catalogs and airline timetables. Subsequent generations of optical disks will offer full read/write capability and pose a challenge to Winchester capacities.

A comparison of different storage devices along with their relative costs is presented in Table 3 [11]. An overview of memory requirements for various applications is shown in Fig. 1. A portfolio of several different types of storage devices provides the desired storage space and retrieval speed at an acceptable price.

Input/Output Devices

All personal computers contain a keyboard as the standard input device. Although almost all computers use the qwert... keyboard layout pattern, the number of keys varies from system to system. In the minimum case, the number of keys is around 50. Additional keys are used as "function keys" and enable an operation (such as PRINT or INSERT) to be initiated by a single key depression instead of having to type in the entire word. Such function keys help in increasing speed of inputs by users and reducing the probability of typing errors. The disadvantage, however, is that the user must be aware of the function performed by each key. Since manufacturers have designed keyboards based on

Table 3 Attributes of Storage Media (Updated and Expanded Version of Table from [11])

Attribute	Floppy Disk	Winchester Disk	Hard Disk	Audio Cassette	Digital Cassette	Cartridge Tape	Video Disk	Video Cassette	Bubble Memory
Storage (Mbyte)	0.3–3	3–30	3–20	0.1	0.5	2.5	10K	20K	0.5–10
Access Time	200–500 ms	20–80 ms	20–80 ms	40 in/s	300 in/s	30–90 in/s	2.5 s	4.5 min	0.5–5 ms
Transfer Rate (Kbit/s)	60	5000	5000	75	2–8	70	750	750	100
Replaceable or Fixed (R/F)	R	F	F	R	R	R	R	R	F
Read/Write	R–W	R–W	R–W	R–W	R–W	R–W	R	R–W	R–W
Drive-Unit Cost	250–500	1000–6000	1000–6000	50–80	500–900	1000–1500	400–750	700–1200	1000–2000
Media Cost	5–10	n/a	n/a	2–10	10	15	15–25	10–15	n/a
Cost/Byte (cents)	0.01	0.01	0.04	0.05	0.1	0.04	0.00001	0.000005	0.5

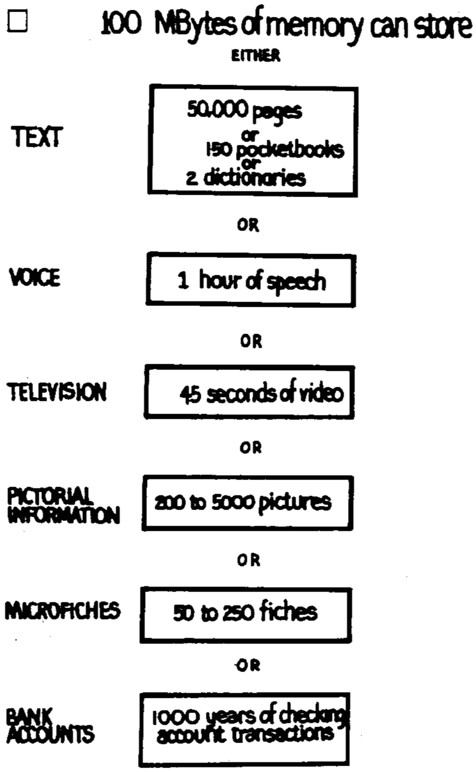

Fig. 1. Memory requirements for various applications.

their own ergonomic studies and with no mutual consultation with other manufacturers, the task initiated by a particular function key differs from system to system. Keyboard designs often have individual idiosyncrasies. For example, on the IBM Personal Computer the RETURN key, the LEFT-ARROW cursor key, and the BACKSPACE key, each performing vastly different functions, have all been clustered in near proximity—further, the key-top markings are also similar causing confusion to first-time users. In personal computers, the keyboard may be an integral part of the computer or a movable self-contained unit connected to the computer by a cable or through an infrared link as in the case of the IBM PCjr [16].

The primary output display device used in all personal computers is a television screen, or a monitor. In both these raster-scan devices, an electron beam is swept across the screen from left to right. The brightness of the screen is determined by the energy of the electron beam and controlling this energy allows display of a horizontal line with varying intensities along the line. During the return sweep from right to left, the electron beam is turned off and hence leaves no trail. The electron beam is again swept from left to right at a position slightly lower than the previous time, and this process of "raster scan" is continued until the entire screen is complete. The process is again repeated from top to bottom thirty times each second. Each scan line is comprised of several hundred sample points called picture elements or *pixels*. The difference between high- and low-resolution displays lies in the number of pixels that can be addressed by the computer. A typical low-resolution number is 128 × 48 (6144 pixels) while high-resolution displays may contain more than 1000 × 1000 distinct pixels on the screen. In such high-resolution displays, more than a million bits of information must be transferred to the CRT every thirtieth of a second, thus involving significant overhead. To reduce this overhead several options are possible. One option is to reduce the frequency of refresh—this causes a "flicker" effect which is irritating to the eye. Another option is to reduce the number of scan lines and scan points—this results in a relatively "coarse" picture being generated. A third option is to use a storage CRT (a CRT which retains brightness levels). Such CRTs are costlier and introduce a heavy overhead when a new picture has to be displayed in place of the previous one. A fourth option is to use a display in which the beam is not constrained to a horizontal path but can move in any arbitrary direction across the screen. These all-points-addressable displays offer advantages in the case of line drawings and vector representation of images.

The television display, though inexpensive, cannot accommodate the 80-character column widths used in business word processing with enough resolution to be easily read by the human eye. Also, in many cases, the availability of colored output offers distinct advantages over a monochrome display (usually white/black, green/black, or orange/black) of equivalent resolution. Currently, medium-resolution color RGB (red, green, black) monitors in the range of $500–$700 suffice for most application programs in the business environment.

Another display technology compatible with personal computers is the *flat screen display technology* primarily used in portable personal computers. In this case, the display is either built in or is configured with the personal computer unit by the manufacturer [15]. Although the flat panel displays and other new products are beginning to appear in volume, the CRT display remains the primary display technology. The CRT market is growing at 25 percent per year and prices are decreasing at 5–10 percent per year.

A part of the computer's own memory or a separate dedicated memory is used to store the information about the pixels on the screen. Such a "display memory" or "frame buffer" can be built with two access paths—the first path is used by the computer to write, and the second path is used for reading by the refresh circuits. Drawing of a new line requires the computer to alter the contents of the memory locations corresponding to the pixels whose states have to be altered. When a *light pen* is used to draw on the screen, the position of the pen is continuously monitored by the computer and, depending on changes in the position of the pen, the computer makes appropriate changes in the display memory. A *mouse* is a similar device, except that its movement on a horizontal plane is monitored and translated into lines on the vertical screen. The mouse represents a simple cursor positioning device that couples the screen cursor to a mechanical or optical rolling device on the table top. *Tablets* are also available for absolute positioning of inputs from a stylus on a grated surface. *Touch screens* using infrared, LED, or grid technology and offering medium resolution are becoming available on many contemporary personal computers. However, the basic principle of operation of all these devices is very similar. The computer detects the movement and makes appropriate changes in the display memory.

In many environments it is essential to have a hard copy, that is, a copy that can be read by human eyes and that will last for several years. A hard copy output is generated using one of four alternative device technologies. At the low end, *thermal printers* provide inexpensive and relatively quiet hard copy output. Disadvantages include the requirement for special paper and the fading of the thermal image over time. *Impact dot matrix printers*, though a little more expensive, produce near-letter quality text, alphanumerics, 100-dots-per-inch graphics, and, in some cases, limited color output. Units in this category tend to be the most reliable and cost effective for business applications. *Letter quality printers*, based on a Daisy Wheel or Spin Writer technology, offer better print quality and also limited graphics capability. At the top end, *laser printers* are available for high-quality text and graphics output. Laser printers have the ability to produce typeset quality text output as well as near-photographic quality graphics. It is only a matter of time before such units become common table-top personal computer output devices. Just as the plain paper copiers have now become personal (e.g., Canon PC10/PC20), so, too, will the laser printer become the common desk-top hard copy output device.

Both in the case of a display and of hard copy, the output must be "read" by the user. Such "visual" perception of computer-generated outputs has continued to be the predominant mode of computer communication with human beings. Computers that could communicate through the medium of "speech," as conceived in *2001: A Space Odyssey*, offer great advantages in terms of ease of use and in enhancing the quality and power of the man–machine symbiosis. Speech can be used to input information to the computer in the form of spoken, rather than keyboard, commands and data. This process, called *voice recognition*, holds special merit for motivating senior executives to use computers and also for handicapped users and in "hands-free" work situations. The complementary process of *speech synthesis* involves synthesizing or replaying of speech through a combination of voice patterns stored in the computer. Toys like the Texas Instruments Speak 'N Spell and many video games embody the latter capability in a rather primitive manner. Also, the spectrum of spoken words is very limited. It is only within the past two years that speech has been used as a viable communications methodology for generalized applications in conjunction with personal computers.

Speech consists of a sequence of discrete sound segments, called phonemes, linked in time. Each phoneme possesses distinguishable acoustic characteristics. A spoken word consists of several syllables, each comprised of several phonemes, with the characteristics of a given phoneme having been modified as a function of its immediate phonetic environment. The latter effect, called coarticulation, causes the same phoneme to have vastly different acoustic characteristics in different words making it difficult to decompose the word into its constituent phonemes. Further, since the coarticulation effect can occur across word boundaries, too, continuous speech is more difficult to recognize than isolated words. The process is further complicated by the fact that pronunciation varies enormously from person to person and even for a single speaker. A summary of the inherent processing requirements for different types of speech is presented in Table 4 [17].

Table 4 Speech-Recognition System Milestones [17]

Recognition Capability	Isolated words, Speaker-Dependent	Continuous Speech, Speaker-Independent	Isolated Words, Speaker-Dependent	Isolated Words, Speaker-Independent	Continuous Speech, Speaker-Independent
Syntax	Limited	Limited	Unlimited	Unlimited	Unlimited
Vocabulary, words	200	1000	5000	20 000	20 000
Processing speed required, megainstructions per second	1 to 10	100	300	1000	100 000
Technology required	Acoustic pattern matching used to identify individual phonemes Dynamic programming to solve problem of variations in duration of words (Both achieved by Nippon Electric Co. commercial machines)	Beam-search strategy to narrow selection of words Better algorithms to determine word boundaries (Both achieved by Harpy)	Probabilistic approach to determine words on basis of preceding words, for use in supplementing phonetics Faster searches using selectors keyed to individual sounds (Achieved by IBM experimental system, but not in real time)	Language constraints—such as the fact that "vn" never begins English words—to narrow choices Relating acoustic signals to phonemes in form of quantitative rules	natural-language understanding Knowledge base to use context of speech to assist in recognition Learning from errors

Because of the enormous computational overhead, the corresponding high costs and low demand, few custom integrated circuits have been developed for speech-related applications. The advent of the Texas Instruments TMS 320 microprocessor [19] used in the TI Professional Computer [18] and in personal computers of other makes has played a major role in equipping personal computers with the capabilities of recognizing isolated words as inputs and of generating outputs in the form of synthesized speech. In view of their lower requirements for computing speed and memory, speaker-dependent systems are more common. In such systems the user first defines the vocabulary of the enrollment phase. Next, the user speaks each word several times to enable the computer to store alternative pronunciations. The system is now ready for use. The system "hears" words spoken by the user and compares them with words in its stored vocabulary database. If a match occurs, the reference word is identified; if not, the user makes a fresh attempt or inputs information into the computer using a more traditional mechanism. The size of the mass storage and its retrieval rate determines the maximum size of the vocabulary. The TI system is capable of recognizing vocabularies of up to 50 words each, with spoken words replacing up to 40 manual keystrokes [18]. Also, it allows for recognition of connected words without compelling the user to pause between words.

Speech synthesis, the process of reconstructing speech from stored digital data, is implemented using one of two approaches. Synthesis by rule, also called "constructive synthesis," constructs sounds from text based on linguistic rules. Variations (allophones) of phonemes are prestored in the computer memory. The size of this stored information and the overall size of the set of linguistic rules are used to define the quality of the sound produced. Comparatively less memory and better sound quality can be generated using the alternative approach of *synthesis by analysis*. In this case, the user must first speak the word, and the corresponding information is digitized and stored. At the time of synthesis, the system uses these digitized patterns to generate a speech output that closely resembles the voice of the original speaker. Unlike synthesis by rule where an unlimited number of words could be synthesized, synthesis by analysis allows generation of only those words which are previously known to the system. Data compression techniques are employed to store more words in available memory without appreciable loss of quality. The most common one is the linear predictive coding (LPC) method. The TI system models the human voice with only 2400 bits/s [18]. This enables storage of 16 min of speech on a 320K-byte diskette and 8 h of speech on a 10-Mbyte Winchester disk. The latter figure is much higher than the unoptimized method of speech storage shown previously in Fig. 1.

Besides communicating with human beings, there is a heavy increase in the level of information exchange between personal computers and between personal computers and host computers (mainframes/minicomputers). Already, personal computers are used in the business environment as intelligent terminals to retrieve files from host computers to be manipulated locally on the personal computer. True networking personal computers operating on a user-transparent basis will become available in the coming years. Currently, many different protocols have been proposed for integration of local personal computer networks. Two protocols that currently dominate the consideration are Carrier Sense Multiple Access (CMSA/CD) and Token-passing. Efficient communication, especially between dissimilar systems, is critically dependent on the protocols and standards for interconnection. Readers interested in the communication aspects of *Local Area Networks* (LAN) may wish to refer to the December 1983 special issue of the PROCEEDINGS OF THE IEEE.

III. SOFTWARE

Between the stage of input of a command or data by the user and the actual execution by the microprocessor, several layers of software come into operation. Undoubtedly the most important, the *operating system*, is used to optimize utilization of resources and to minimize user effort. In addition, there are programming languages and their development tools and user application packages. We consider the operating system first.

Operating System

An operating system is a software program, usually provided by the vendor, that is used for some or all of the following functions:

a) processor management
b) memory management
c) peripheral management
d) file management
e) task scheduling and process management
f) user-oriented facilities such as command-line interpretation
g) miscellaneous functions to support networking, utilities, and high-level languages.

Unlike mainframe computers where the emphasis of the operating system is towards optimizing the usage of the CPU (deemed to be the "costliest" resource in the system) and to support multiple users, operating systems for personal computers are geared more towards supporting single users only and high CPU utilization is no longer the primary objective.

The history of operating systems for microcomputers commences a decade back (1974) when MAA (Microcomputer Applications Associates, later to become Digital Research) developed a small operating system called CP/M (Control Program for Microcomputers). This program enabled applications to be written and compiled on an Intel 8080-based microcomputer. Because of its significant head start, CP/M has become one of the *de facto* standards with most vendors in the United States and Japan which support it on their 8- and 16-bit microprocessors. Another *de facto* standard is the MS-DOS operating system developed by Microsoft—this operating system was introduced in August 1981 in conjunction with the IBM Personal Computer and as such is also called PC-DOS. Its future as a viable standard has been guaranteed by the large base of personal computers of IBM make and the array of plug-compatible hardware from other manufacturers.

A third *de facto* standard is the UNIX operating system. "The name UNIX is a weak pun on Multics" [20]. After Bell Laboratories withdrew from the Multics project at MIT, Kenneth Thompson, an employee of Bell Laboratories, began to implement his ideas about a small but powerful operating system on a discarded PDP-7 computer in 1969 [21]. Originally implemented in assembly language, this operating system was re-implemented in the early 1970s in 'C' programming language on different models of PDP and in the late 1970s on many computers of other makes. The availability of UNIX on personal computers enables these computers to use software originally developed for execution on minicomputers. UNIX offers advantages in multitasking and multiuser environments and hierarchical file systems. Also, it supports linkage and integration of information in a LAN environment.

One of the unique features of UNIX is its "Shell," which allows users to process several system commands with minimal effort through the execution of user-developed Shell files. Nesting of these files further enhances applicability. The Shell provides a common syntactical format for all system commands and utilities and enables support of several specialized capabilities: *pipes/filters* for passing information between processes; *metacharacter* processing for increasing system flexibility through the use of special characters; and *background process generation* for execution of jobs in the background while the user continues to perform other processes without apparent interruption. UNIX uses a hierarchical file system with three distinct categories of files: *ordinary files* are files created by users and contain user-designated information; *directories* provide mapping between the names of files and the files themselves; and *I/O oriented files* are used within the UNIX structure to denote system devices such as terminals, disk drives, and printers. One drawback of UNIX is its terse command structure. For example, CP means COPY, and RM (for remove) is used to delete files from a directory. But this minor esthetic deficiency can be easily circumvented, and UNIX, overall, is indeed a powerful operating system for multiuser environments.

CP/M on the other hand uses ordinary disk files which can be accessed on either a sequential or random basis. CP/M consists of three main subsystems: *BIOS* (Basic Input Output System) which handles input–output operations and is heavily hardware dependent; *BDOS* (Basic Disk Operating System) which handles all file transactions and is machine independent; and *CCP* (Console Command Processor) which handles operations relating to the user console. Since CP/M is intended for single-user operation, there are no commands to assign priorities to programs or to enable transfer of information between processes. On the other hand, CP/M offers a Dynamic Debugging Tool (DDT) to facilitate debugging of errors.

The structure and facilities of MS-DOS are quite similar to those of CP/M. Both are intended solely for single-user operation, and as such perform the minimum set of functions usually associated with an operating system. In view of the growing popularity of networks of personal computers and the use of multiple processors within the same personal computer, it is inevitable that UNIX is becoming increasingly important because of its inherent orientation towards multitasking and its acceptance by major manufacturers of microprocessors [24]–[27].

There are two parallel trends in developing the UNIX operating system. Several companies including Microsoft have adapted the code, developed by Bell Laboratories, for several microprocessors. Other companies have opted to rewrite the entire code based on the UNIX design. Meanwhile, Digital Research has expanded their CP/M operating system to support multiuser and multitasking environments. This expanded system is called MP/M.

Even when the same operating system is supported on different computer systems, hardware and architectural differences make it essential to modify application programs to execute under the same operating system on different computers. To mitigate such problems in the migration of software, the UCSD p-system [22], originally developed at the University of California at San Diego, facilitates software portability through use of intermediate code, called p-code, into which all the high-level languages are compiled. Interpreters are available for many processors for translating p-code into the respective native code of the processor. Using this strategy, the same source program can be executed on different systems. The penalty is in terms of reduced execution speed of interpreted code. As microprocessors offer increased speeds and as programming costs continue to escalate, more users will accept the penalty of reduced execution speeds and opt for solutions using such techniques of intermediate code to achieve software portability. The concept of p-systems has been enlarged to establish a network protocol for computers of different makes. Each mode of a network in such a system is assigned a different function [31].

Application-Oriented Software

Application packages fall into two categories: *specialized packages* oriented towards a specific task or operation, such as payroll or inventory, and *generic tools* used to develop customized models or personalized solutions to problems. Packages in this latter category of "fourth-generation languages" permit the user to develop a structure for his or her data and to perform specific operations on the data. These fourth-generation language tools are extremely powerful and flexible for solving *ad hoc* problems.

Conversion of mainframe and minicomputer software to a personal computer environment represents an interesting challenge. The limited capabilities of the personal computer do not, in general, allow for a mainframe software package to be transported in its entirety to a personal computer. Also, it is not always desirable to move the entire mainframe package as in the case of centralized databases. Frequently, the personal computer will perform all of the terminal emulation, screen handling, and query preprocessing and postprocessing functions. The mainframe retains responsibility for database access, security, and query response. Thus tasks formerly hosted on the mainframe alone can now be split between the personal computer and the host computer to provide more efficient and quicker user response. Such partial migration of software is becoming increasingly prevalent.

Principal *program development languages* in use today are Basic, Pascal, C, Fortran, and Assembly language. Although Basic is a convenient and easy language in which to prototype algorithms, it lacks structure, self-documentation, and flexible program linkage conventions to make it an efficient application development tool for any but the simplest of programs. Pascal facilitates structured programming and documentation. The key tradeoff between Pascal and C is the strong versus weak typing of data provided by each, respectively. The former is preferred for applications programming while the latter has strengths for systems programming. Pascal and C are not as easy to learn as Basic. Fortran is a carry-over from minicomputers and mainframes. Assembly language offers high performance, compact code, and intimate control of the hardware. It is used in cases where real-time requirements, input–output device control, and graphics manipulations require programming at the machine level. In many cases, a high-level language is used to develop the general structure and key algorithms, and Assembly language is used to provide specific performance enhancements and device control not achievable in the high-level language. As the costs for software program development become astronomical in terms of programmer time, documentation, maintenance, and field support, off-the-shelf packages are becoming increasingly preferable over in-house software development.

With more than half a million copies having been sold so far, VisiCalc represents the most popular personal computer applications program. Developed by Daniel Bricklin and Robert Frankston in 1979, this "instantly calculating electronic worksheet" uses computer memory and a CRT terminal to store and display a table of 63 columns and 255 rows. Each position of the matrix on the screen corresponds to a record in memory. Each record in memory holds either data, a label, or a formula. The corresponding position on the screen is used to display the label, data, or the result of the calculation using the formula. For example, if the record D8 (D refers to column number and 8 to row number) contains the label "CASH," then at position D8 on the screen the word CASH will be displayed. The same is true for data. The power and flexibility of VisiCalc becomes clearer when we consider what happens with a formula stored in memory. For example, if record A5 contains the formula +A1 + A3, the results of adding the contents of records A1 and A3 will be displayed. If the data in A1 or A3 are changed at any time, the answer displayed at A5 will change automatically. The contents of records A1 and A3 need not be data; they can also refer to another location via a formula. This enables formulation of a particular problem using records as variables. At any given time, 20 rows and up to nine columns are displayed facilitating comprehension of relationships among entries.

Initially, personal computers were used primarily for calculations and for numerical work. The last three years have witnessed the growing popularity of word processors and text-manipulation applications such as checking spellings using extensive dictionaries resident on floppy disks. Only now is it becoming feasible to efficiently undertake storage and retrieval of graphical and pictorial information. In coming years, software will become available to perform integrated sets of operations involving diverse types of information—numbers, text, and pictures [28]. Just as the evolution of integrated databases drastically altered the manner in which information was maintained on mainframe computers, the integrated manipulation of dissimilar information structures will revolutionize the role of personal computers and widen the scope of application areas as shown in Table 5.

The evolution of sophisticated graphical and pictorial representation techniques in the limited memory space of personal computers is made possible using several innovative ideas. Logo, a graphics-oriented language designed for school children arose from the Lisp programming language devised at MIT. By building up primitive structures using a cursor—a "turtle" in Logo nomenclature—and integrating them, Logo attempts to introduce thrills, rather than frustrations, in generating complex drawings using personal computers. At the other end, the idea of visual "icons" originally implemented on the Xerox Alto [2] has now been introduced in the realm of personal computers on systems such as the Apple Lisa [29]. The implementation strategy used in VCN ExecuVision [28] reflects an example of an endeavor to implement sophisticated presentation graphics capabilities on inexpensive computers, and to use contemporary data compression techniques to store hundreds of images on a single floppy disk.

The spurt in the number of software products is compelling software developers towards common data structures to enable transfer of information between different programs. The VisiOn Operating Environment [32] is one such example of a unified system that integrates applications programs and presents a common and consistent user interface. Just as portability and standardization of operating systems are now receiving attention, application programs are also undergoing a slow, but distinct, trend towards rationalization and maturity!

IV. Architectures

Contemporary personal computers are marked by significant diversity in terms of their architectures and level of performance. Even in the case of the same manufacturer, architectures may differ radically from system to system as in the case of Apple Lisa versus Apple II.

To a large extent, the architecture of the personal computer is dependent on the microprocessor used to handle principal activities. The choice of a particular 16-bit [8] or 32-bit [9] microprocessor as the CPU of the personal computer determines the maximum size of memory, the manner of interconnecting input–output devices, and the "optimal" program development environment for the system. Several personal computer vendors including IBM [16], DEC [13], and Wang [34] have opted to use microprocessors belonging to the Intel iAPX 86 family, and it is hardly surprising that these personal computers possess similar architectures. The Motorola 68000 finds use in the HP-200 [1] and the Apple Lisa [29] systems.

However, even in cases where the same or a similar chip has been used in several systems, the end products are not necessarily identical. The compatibility aspect between members of the IBM Personal Computer family is examined in [16]. In general, differences in architecture are due to several reasons including personal preferences of different designers, the availability of newer co-processors and higher density memory chips, and the perceived user needs. There is now a growing trend towards using several dissimilar microprocessor chips within the same system in order to

Table 5 Personal Computer Applications

Past	Present	Future
Calculator-Type Functions	Simple Data Retrieval	Integrated Information Retrieval
Hobbyist	Basic Accounting and Spreadsheet	Decision Support Systems, e.g., medical diagnostics, legal information
Games	Elementary Graphics	Artificial Intelligence, Distributed Databases

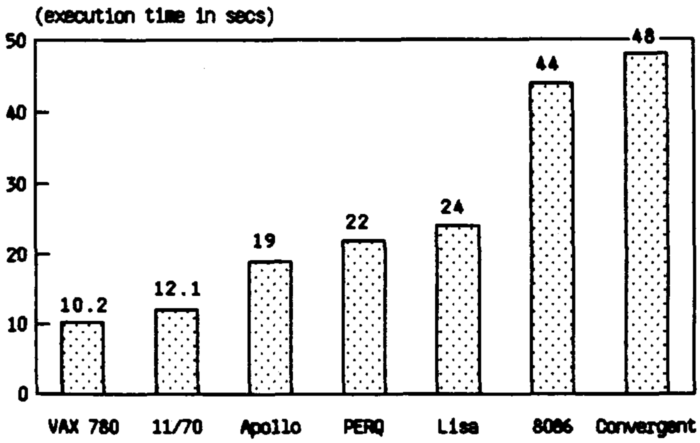

Fig. 2. Performance evaluation using Pascal "PUZZLE" program.

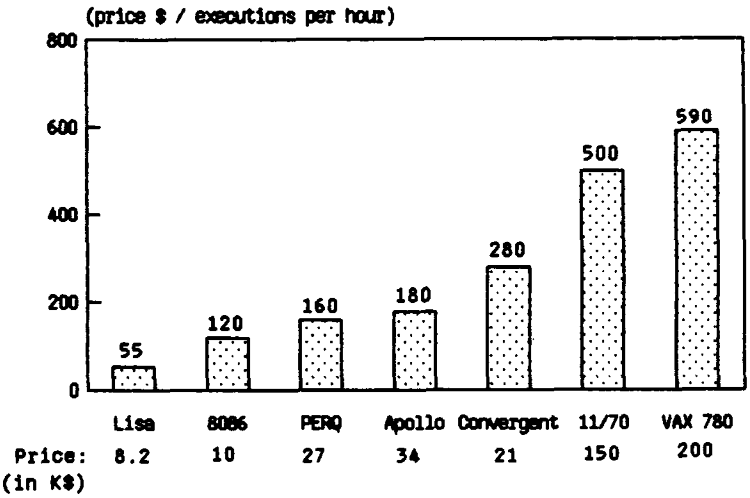

Fig. 3. Price/performance ratio for "PUZZLE" program.

allow different operating systems to run, or to handle different functions [13], [14]. In such cases, efficient mechanisms are designed to handle communications between the multiple microprocessors.

The use of dual-ported memories represents another area of innovation. Since the screen must be refreshed at regular intervals, the memory must be read at a constant rate. In parallel, the computer is also writing to and reading from the memory. Dual-ported memories allow both these functions to occur in parallel, without compromising either the throughput of the computer or the refresh rate of the display. The PC 100 manufactured by NEC performs these functions in parallel without using expensive components [33].

Because of their orientation towards ease of use rather than on raw computing speeds, manufacturers have published little information about standardized applications level throughputs of their respective systems. Macro-level comparisons between the DG and IBM personal computers have been indicated in [14]. Similar comparisons between the DEC Rainbow and the IBM personal computers found in [35], [36] show that these two systems have performance in the same ballpark range. Figs. 2 and 3, provided by Apple [30], show the relative performance and the price–performance ratio of the Apple Lisa in comparison to minicomputers and other computers not falling within the category of personal computers.

Independent evaluation of several different personal computers is still scarce. The spectrum of options on each system, both in terms of hardware and software, restricts the usefulness of such results. As such, some comparisons simply summarize the specifications in terms of features. One such comparison of portable computers [37] shows the spectrum of functionality available on personal computers. Similar comparisons of desk-top computers appear frequently in trade journals. The fast rate of introduction of new personal computer products represents a rapid evolution of traditional mini/micro architectures towards new, innovative system organizations to best utilize the new technologies and best support the end user. By offering performance traditionally available on much larger systems, personal computers are gradually eroding the popularity of minicomputers and even mainframes!

V. Markets

The application of personal computer technology varies substantially between the four areas of usage: home, business, science, and education. Users in any given area have specific needs and expectations as shown in Table 6. Accordingly, manufacturers of personal computer systems as well as software vendors have targeted specific offerings to each of these markets. The major functional requirements of each of these four categories are defined below:

Table 6 Four Primary Markets for Personal Computers

Characteristic	Home	Business	Science	Education
Complete System Price ($)	≤ 1000	≤ 5000	≤ 10 000	≤ 1000
Overall Need for Storage				
a) Avg. System Primary	64K	256K	256K–512K	64K
b) Avg. System Secondary	100–500K	0.5–1M	5–10M	500K
Computation Intensive	Low	Moderate	Heavy	Low
Hard Copy Output	Dot matrix printer	Dot matrix letter quality	Full graphics	Dot matrix
User Interface	For noncomputer use of graphics, color	Noncomputer user	Computer user	Use of graphics color
Applications Software Price	≤ $100	$100–700	$1000–2000	≤ $200
Principal Applications	Games, household tasks, word processing	Spreadsheets, word processing graphing database communications	Similar to business applications; Specialized to each task	CAI, CBT, Classroom instruction

Requirements of the Home Market

a) Low Cost: The home market is very price-sensitive to both hardware configuration costs as well as add-on software expenses. Because it is a consumer market, personal computer technology must be packaged, marketed, and distributed in the same fashion as mass product consumer goods. Price resistance occurs at several levels. For the hardware system these levels are around $100, $500, and $1000. The upper limit on home budgets for a basic computer system is around $1000. Similarly, in software, the home market centers between $25–$50 for entertainment packages and between $50–$200 for home financial applications.

b) Expandability: The ability to expand the original system by the addition of peripherals, more memory, or communications, and the availability of a growth path to upwards compatible, more powerful computer systems are factors that influence the decision to purchase a computer system.

c) Educational Software: Aside from entertainment, personal computers are used for training and education. This includes learning of Basic, elementary mathematics, reading, and other school skills and the use of educational programs at the secondary school level.

d) Games: Home computers support entertainment and game software. This application requires the generation of colors and sounds in the system unit.

e) Integration with Other Home Systems: Facilities must exist for the computer to be hooked up to the home entertainment system that currently includes the television set and in the future will include stereos, large-screen TVs, telephone, and data network services such as Videotext.

Requirements of the Business Market

a) Storage: Business applications require sufficient on-line and secondary storage to accommodate moderate to extensive databases. On the average, current-generation business personal computers use 128K bytes of RAM, with secondary storage around 1 Mbyte for floppy technology and 10 Mbytes for hard disk Winchester technology.

b) Hard Copy Output: The need to produce reports, memos, and graphs in a form suitable for presentation to other parties requires capabilities for both letter quality text as well as high-resolution graphics output. These two requirements necessitate separate types of printer technology driving up the price of business computer systems.

c) Large Software Base: The average business person has neither the expertise nor the resources to develop software in-house. Consequently, such users invest heavily in off-the-shelf software applications programs. Hardware that supports a variety of editors, word processing programs, spreadsheets, graphics, and database programs is naturally preferred.

d) Support: The impact of a system "going down" is much more serious in a business environment than in the home. Thus business users require sufficient support from either the vendor, the distribution channel, or an in-house information center to achieve reasonable "up-time" characteristics.

Requirements of the Science Market

a) Specialized Systems: Scientific users often have a need for special hardware devices and specific software within a narrow application area. For example, the use of a personal computer in a research chemistry laboratory would require interfaces to various noncomputer equipment (e.g., gas chromatographs, multichannel analyzers, spectrometers), and specialized software to integrate the auxiliary systems with the personal computer. If no off-the-shelf software exists, then the scientific user seeks good programming and debugging tools in order to develop software in-house.

b) High Computation Requirements: Since most applications are computation-intensive, the personal computer must provide fast numeric calculations as well as efficient block data moves, possibly through the addition of a coprocessor dedicated to arithmetic and floating-point operations.

c) Programming Environment: Because scientific users often do their own program development, the programming environment must be rich and flexible including tools such as full screen editors, symbolic debuggers, and extensive cross-reference capabilities, and efficient run-time packages.

Requirements of the Education Market

a) Ease of Use: In order to retain the motivation and the attention of students, personal computer systems must present a friendly interface and challenging, easy-to-use software.

b) Cost: Educational institutions are in a period of shrinking budgets and thus are unable to afford high-end systems.

c) Educational Software Base: The personal computer must support self-paced computer-aided instruction (CAI) programs and a large educational software base.

d) Environmental Factors: The classroom environment requires sharing of most personal computer resources in order to reduce the cost per student to an acceptable level. This sharing is enforced by scheduling, by local area networking, or by hardware multiplexing. Another requirement is the need for portability as the personal computer is often used by different groups for different topics at different times within the same institution. Finally, units must be rugged to survive in an educational environment.

The overall trends in the four principal markets in terms of price per system, number of systems, and total dollar volumes are summarized in Tables 7, 8, and 9, respectively.

Table 7 Historical and Predicted Average Price for Personal Computers in the U.S. for Different Applications

Year	Business	Home/ Hobby	Science	Education	Overall Average
1981	$3599	$1997	$3199	$2800	$3099
1982	$2630	$1240	$2355	$1987	$2186
1983	$2502	$1071	$2432	$1325	$2047
1084	$2238	$ 787	$2642	$ 935	$1807
1985	$2182	$ 778	$2696	$ 712	$1752

Table 8 Estimated Number of Units Sold/Projected to be Sold: By Market Segments: U.S. Only (in thousands)

	1980	1981	1982	1983	1984	1985
Business	285	385	750	1040	1500	2100
Home	135	175	375	510	750	1075
Science	60	105	200	250	300	400
Education	20	35	60	100	150	225
Total (numbers)	500	700	1385	1900	2700	3800
Total Value: (millions of dollars)	(1140)	(2169)	(3028)	(3889)	(4880)	(6658)

Table 9 Total U.S. Market (in Millions of Dollars)

Year	Business	Home/ Hobby	Science	Education	Total
1977	26.5	25.2	8.2	3.1	63
1978	140.25	82.5	38.5	13.75	275
1979	385	175	105	35	700
1980	681.7	228	173.3	57	1140
1981	1385.6	349.5	335.9	98	2169
1982	1972.7	465.1	471	119.2	3028
1983	2602.2	546.3	608	132.5	3889
1984	3356.8	590.2	792.7	140.3	4880
1985	4582.6	836.8	1078.5	160.1	6658

VI. Conclusion

The personal computer is a product of the information revolution. It usually requires a substantial amount of time to disseminate any product of a revolution among the population at large. The benefits of the industrial revolution accrued many decades after the original inventions. In the case of computers, this dissemination process has occurred over a very condensed time frame.

The domain of individually tailored computing power has evolved dramatically over the past decade, and the impact of this evolution continues to escalate. The shift in focus from computing power to ease of use has led to concentrated efforts in evolving user-oriented mechanisms such as function-keys, menu-driven interfaces, speech input and output methodologies, and fourth-generation languages. The selective combination of these newer techniques has resulted in a wide variety of personal computers to suit the needs and the economics of different individuals. As in the case of other consumer items, such as cars, a prospective user appreciates the utility of acquiring an asset. However, the process of selecting and configuring a personal computer is becoming increasingly complex [38].

Most people involved in scientific, engineering, or business endeavors combine activities that fall under several categories. A typical user will employ the personal computer to prepare and disseminate office memos, professional papers, and data records, to support decision making, and also to learn new skills of both an educational and entertainment nature. The flexibility of a personal computer to carry out such a multitude of functions is what makes it so convenient and desirable to most of us. From the quiet beginning of the personal computer, one could have hardly visualized that within a single decade this technology would be available in a product form to several million people around the world and will become available to many millions more in the very near future. In this article some notions about the second decade were presented. No doubt things will look very different by the turn of the century, but hopefully we will view the personal computer with as much excitement, promise, and enthusiasm as we foresee today!

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