demand printing are examples. It is important to recognize that the last two roles depend principally on the development of useful computer software, and only secondarily on the ability to communicate among computers.

We have chosen to concentrate on the basic structure of computer networks and the underlying features that seem to govern their character: (i) the hierarchical structure building up from the underlying datagram primitive to network tools to collections of tools that perform scientific functions; (ii) the integration of network tools with computer tools generally in order to obtain the various benefits, so that networks are not to be evaluated as isolated functions; and (iii) the laissez-faire manner in which network (and computer) tools will grow, with attendant luxuriance in opportunities but roughness in execution. We have not been careful to enumerate all or most of the tools and existing scientific networks. They are part of the current scene, which—if anything is clear at all—will change complexion rapidly.

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Computers and Electronics for Individual Services

Ruth M. Davis

Individuals have long used computers to perform personally needed services. Today, the term personal computer generally refers to a computer system that fits on a table or desk top, is in the price range of a consumer product, and is marketed for a wide range of popular, personal applications. Memory size, computing power, and display capability do not definitively characterize the personal computer because they are rapidly changing.

The advent of personal computers can probably best be viewed as another step in the continuing development and diversification of the computer field in terms of both products and applications. Like the minicomputer and the microprocessor before it, the personal computer appears to be ushering in a new era in computing history. Although it was long anticipated by computer professionals, to the new customer to whom computing power was not previously available personal computing opens the door to a variety of new activities. Probably the greatest change brought about by personal computing is that it takes the computer from the exclusive province of scientists, engineers, and company professionals and makes it available to almost any individual in any environment.

Ten years ago, saying that the computer offers to the individual the ability to significantly control his immediate environment might have been considered whimsical. Today, it is an observation that can be supported by many examples. In discussing personal computing in this article I will use some examples from areas that were not previously affected by computers, including entertainment, home management, and mail as an individual means of communication.

Genesis of Individual Computing

There are probably three principal factors that have contributed to the increasing popularity of individual computing devices. One was the provision, beginning in the 1960's, of "carryable" terminals that professionals could use at home to carry on office computing tasks through remote access of computer systems. The second, which was due to dramatic decreases in the cost of electronic equipment, was the advent in the early 1970's of home computer kits with which one could build computer and computer display devices. The third, also originating in the early to middle 1970's, was the availability of electronic games on coin-operated machines or home television sets.

The instructions accompanying a microprocessor kit I bought in 1980 explained the principles and use of semiconductors and programming with pictorials and a minimum of engineering jargon. Written in the middle 1970's, they already identified sample uses of the assembled kit such as temperature control, cooking control, credit verification, portable computing, surveying, traffic control, "smart" toys, and electronic bartending. This material exhibited many of the elements of friendliness that home computer sellers are still trying to project for their products.

The first (cumbersome) carryable remote computer terminals were replaced in the past 15 years by smaller portable keyboard input-output terminals and display input-output terminals. Each type was accompanied by an acoustic coupler through which it could be interconnected

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by telephone with one or many computers located elsewhere. These remote terminals grew into the home or personal computer without any real increase in equipment size. Further, today's home computer costs no more—and in many cases less—than its terminal ancestor of the 1960's.

The computer kit began to be replaced in 1977 by already assembled computers. Intel led the way in microprocessor (computer-on-a-chip) technology in the very early 1970's, and in 1977 Processor Technology marketed the assembled Sol-20 home computer. Nolan Bushnell was perhaps the first to popularize the computer game with his electronic game "Pong" (*1*), and Atari, the company founded by Bushnell, is a household word in the electronic game market. Other early personal computers were the Apple, PET, and the Radio Shack TRS line.

In the 10 to 15 years during which personal computers have reached market maturity, their customer following and accepted uses have increased remarkably. Originally, computer buffs were the buyers; now the customers are too diverse to permit categorization—they are almost all of us. The individual computer has changed the entertainment habits of America, it is making its owner's environment more secure, and it is aiding creativity and learning at the individual level. It is becoming possible for the entrepreneur to escape from the burden of financial management and clerical work, and for individuals to bank and shop remotely despite the obstacles of sickness, age, and bad weather. In the following sections I will discuss a few instances in more detail after first describing the technology.

Individual Electronics and Computers

The phrase "electronics and computers for individual services" describes a broad field and would not convey the same meaning to different individuals. Further, the field is expanding at such a rate that any definition must be short-lived. As soon as a new product is introduced, some individuals find more applications for it than were envisioned by the manufacturer; the designer is then motivated to create another product to match the new application, and the innovative spiral continues. In this field we are witnessing a process similar to that which followed the invention of the radio or the automobile. When the products of a new technology are affordable to many individuals and are open-ended in their use, they fire the imaginative spirit of individuals and we see a surge of innovation.

In the case of electronics and computers, the equipment has been dropping so dramatically in price that affordability may be a minor consideration by 1985. The electronic capability exemplified by a typical minicomputer cost $50,000 a few years ago, now costs $3000 to $5000, and is expected to be priced at about $500 in another 3 or 4 years. In addition, the size of this equipment was such that it needed a dedicated room 5 years ago. Now it fits on an ordinary table or a dedicated desk. Some of the important auxiliary equipment is decreasing similarly in size and cost.

An example is the "backyard" satellite antenna, through which individuals can communicate through domestic communications satellites. A decade ago the antenna and terminal equipment required cost about $500,000. In 1980 the cost for a one-channel satellite antenna hookup ranged from $10,000 to $50,000 and the diameter of the antenna dish had decreased from about 25 feet to 10 to 12 feet. In 1982 one can buy a kit for a 12-foot antenna terminal link for $2500 to $7000. About a dozen companies are applying to the Federal Communications Commission for permission to launch high-frequency direct broadcast satellites with signals powerful enough that dish antennas 2 feet in diameter will be adequate. According to COMSAT, which was the first to apply for this direct broadcast satellite system (December 1980), those antennas will cost about $100 (*2*, *3*). The availability for home use of this type of communications equipment coupled with "smart" electronics is certain to provide a breeding ground for applications.

The usefulness of the word computer is diminishing as we become accustomed to products that can calculate, control, play games, "talk," make music, protect, and manage and do so at the direction of an individual, not just an organization with large financial resources. The phraseology to which we have become accustomed over the last 30 years in describing computer architecture is also becoming a trademark of the past as individualized electronic products with widely varying configurations and functions become part of our lives. Perhaps a better term for the present-day technology is electronic logic, a phrase used for at least 5 years to describe smart electronic devices that follow no strict architectural pattern and are sized to meet the physical requirements of the product in which they are embedded.

Summary. Personal computers priced for the consumer market have a wide range of applications and variable memory, computational, and display capabilities. The genesis of individual computing devices, some of their applications, and the market for personal computers are discussed in this article.

The electronic home. The more common applications of electronic logic devices in the home include all those in which the personal computer is used primarily in a typical computer mode; the most popular example is the electronic game. Others that are not yet common include the household robot, the home musical workshop, the total home security and protection system, and an electronic mail system geared to the individual. The thought of a home equipped with a multitude of electronic devices is exhilarating to some and depressing to others. For those who find the electronic home difficult to contemplate, it might be comforting to note that the average home already has some 30 electric motors interconnected by the electric system (*4*). This environment is not frightening to most of us, and familiarity long ago bred compatibility. Using this analogy, it is not difficult to picture 30 electronic systems (say 30 microprocessors) providing greater comfort, entertainment, and safety without disrupting our home activities. Examples already on the market include thermostats, security systems, energy management systems, telephones, video recorders and players, television games, and microwave ovens.

Typical Equipment Units

Some equipment units that are common to most personal computers now on the market are the following:

1) An input device to transmit instructions, information, or programs to the computer. This is normally a keyboard with 70 to 90 keys. It may be an integral part of the computer or a movable self-contained unit connected to the computer by a 2- to 6-foot cable.

2) A display device to print out what the computer is communicating back, either as questions or answers or status. The display is sometimes a cathode-ray

tube (CRT). It may also be a standard black-and-white home television set. The CRT is usually a 12-inch display.

3) The central processing unit (CPU) consists of the logical and arithmetic units of the computer along with a "permanent" main memory in which the operating system, diagnostics, and other core programs are stored. This memory is often read-only memory (ROM) with a capacity of about 32 to 40 kilobytes. (Word length is most often 8 digital bits or 1 byte.) The CPU is a high-performance microprocessor with a clock speed commonly in the 4-megahertz range.

4) The memory unit generally consists of 5¼-inch floppy disk drives, allowing a maximum capacity at present of 256 kilobytes of random-access memory (RAM) in 16-kilobyte steps. External pluggable disk storage units with up to 2 million characters are available from at least one supplier.

5) A printer, either a matrix printer or an impact printer.

Basic configurations containing the units described above are available in a narrow price range, from just under $3000 to slightly over $5000.

Optional equipment that is available for personal computers includes speakers to produce tones, color plotters, joysticks for displays, electronic game program packages, videodisk players, acoustic couplers, and modems for direct connection to the telephone line. I priced basic systems with accessory units including a "letter quality" word-processing printer, a color display, the maximum memory available (several million bits), word-processing software, and financial software packages such as "accounts receivable." In no case was the price higher than about $10,000 to $11,000.

The basic system outlined above is more powerful than those used in the 1950's to control air defense systems and to maintain and analyze the 1950 census data; it is more powerful than computers of the early 1960's used to design nuclear reactors and compute large economic models. Costs for these earlier computer systems were in the multimillion dollar range. The weight of the heaviest unit in a typical personal computer is about 20 pounds. The components of its predecessors were movable only with carts or dollies.

Electronics and Music

Computers and music are not strangers. In the 1950's, amplifiers were connected to computer circuitry and a recognizable but hardly musical tune could be programmed and "played" over speakers connected to computer output terminals. Since then, computers have been used to compose music in two different ways (*5*). The first is composing by using programmed rules of composition and printing out the resulting song or symphony. The second way is for a composer or musician to "play" a computer keyboard, which provides inputs to the computer that are interpreted by the computer's program. The output of the program then controls a synthesizer connected to an amplifier and speaker, which produces the music the musician is playing in real time—that is, as if the computer and its attachments were a traditional musical instrument.

Computer technology contributed the computer, the art of programming, and the digital-to-analog converter, which produced music with traditional amplifiers and speakers. The digital-to-analog converter of the 1960's has become the electronic synthesizer of today; but the modern electronic synthesizer is the product of the rock bands, studio broadcast professionals, and electronic music pioneers of the 1960's. The Moog analog synthesizer, for example, was designed by Robert Moog with encouragement from John Eaton of the Center for Electronic and Computer Music at Indiana University (*6*).

The personal computer has served to bring together the worlds of computers and music to provide the individual with more "instruments" for his own use, more music composition tools, and a first-of-its-kind music "workshop" that invites creativity on a wide scale. The individual has a number of choices to suit his musical taste. For example, those who like keyboard instruments can choose a four- or five-octave keyboard that can be plugged into one of the more popular home computers. The electronic synthesizer consists of one or two circuit cards in one case and either a microprocessor or a synthesizer module in another case. The synthesizer component is also plugged into the computer. With a stereo amplifier the individual can hear what he is playing.

The same combination of computer and electronic synthesizer, along with the required computer programs, allows a number of instruments to be played and recorded simultaneously, so that an orchestra selection can be programmed and played, as is now widely done on television, or composed and played by an individual in his home.

Such electronic capabilities can be expected to stimulate inventiveness. For example, tempo (or timing) and expression are essential for playing an instrument. Four years ago H. G. Alles of Bell Laboratories invented a keyboard that is sensitive to the velocity and force with which the keys are touched (*7*) and translates this speed and force into tempo and expression in computer music. A keyboard with these features now costs less than $1500.

Finally, electronic music has the advantage that stereo earphones can be substituted for the stereo amplifier, allowing the beginner or the musical experimenter to play a single instrument or compose and listen to an orchestra selection without disturbing his family or neighbors. The popularity of electronic music composition for home use, however, remains to be tested.

Electronic Mail

Electronic mail is often said to be an answer to many of our mail service problems and personal communication needs. It has been in the offing for several years. In 1979, Postmaster General Bolger requested presidential policy guidance on electronic mail services (*8*). The concern then was meeting conditions that would ensure full and fair competition. A number of forms of electronic mail had already been tested by the Postal Service, but its introduction was delayed by regulatory problems.

In September 1980 the Postal Service implemented its first version of an electronic mail service, INTELPOST (International Electronic Message Service). INTELPOST permits customers to transmit and receive facsimile copies of original messages, graphics, and other correspondence (*9*). Domestic satellite telecommunications lines were set up between Canada and Washington, D.C., and New York City (*9*). E-COM (Electronic Computer Originated Mail), the Postal Service's second version of electronic mail, began in January 1982. Messages are electronically transmitted by private carriers, and the Postal Service will deliver billings and other computer-generated information. E-COM will be a new subclass of first-class mail.

These mail services would not be considered true electronic mail systems by other industries or by most technologists. A definition of an electronic mail system by the communications industry is one that uses a communications network (transmission and switching) and a terminal device to deliver (display, print) information to an addressee. Voice communication in real time is generally ex-

cluded, although voice communication separated in time is included as electronic voice mail. According to this definition, INTELPOST and E-COM are electronic mail systems between local Postal Service offices, which are intermediary addressees; the final addressee's mail is delivered in the traditional manner.

A more restrictive definition by the electronics technologist would involve "instant" message delivery between sender and receiver at their computer terminals, with no intermediary such as the local post office. Computer networks have given their users the advantages of electronic mail for about 15 years. Widespread use of computer networks as electronic mail systems is more recent.

Voice mail services separated in time can take a variety of familiar forms. A voice message system, for example, allows a home subscriber to record a voice message at a central phone office from his home telephone. The message is later played to the recipient over his telephone. Call answering services are the best known and most widely used today. Advance calling, where a message is recorded to be delivered at a later time, is less common, although it is increasing in popularity. Some voice mail services now digitize the recorded voice message, store it in buffers, use voice compression where appropriate, and transmit the digitized voice signal at much greater speeds than would be possible with ordinary (analog) voice. The VMX (Voice Message Exchange) system of Electronic Communications Systems was the only such digital system commercially available in July 1981.

The home computer greatly increases the attractiveness of electronic mail systems. Such computers used as word processors, generators of reports including graphics, or with copiers or printer terminals can transmit enormous amounts of information electronically. When connected to computer networks or interconnected directly through transmission systems, the personal computer has led to renewed interest in electronic mail systems.

There is a growing tendency to consider the telephone and postal service as media of the past and a growing belief that individuals will need to communicate far more effectively to compete or even to live comfortably. The utility, even today, of electronic (including voice) mail systems is illustrated by the estimates (*10*) that more than 50 percent of the information transmitted by telephone does not require interactive communication, and as much as 50 percent of a manager's time is spent communicating with others by telephone, in meetings, or by written correspondence. Thus, electronic mail systems seem to promise mechanisms for improving productivity and relieving common forms of "office stress."

Personal Computer Market

Markets for the products and services mentioned in this article are not yet well reported. The market for the personal computer or home computer is the best described. Twenty-five U.S. companies sold personal or home computers in 1981. The two largest suppliers, Radio Shack and Apple, sold more than 350,000 computers in 1980, and this sales volume was approximately doubled by the industry in the first half of 1981. Extrapolations from these and other estimates indicate that the number of personal computers sold in 1981 was 1.5 million to 2.0 million, or one per 100 to 150 Americans if all sales were domestic.

In several respects the marketing of personal computers differs from the computer market of the past 25 years. The large mainframe computer companies were the sole marketers of their products; marketing staffs were central in their operations and companies or organizations were carefully targeted and ranked as potential buyers. The successful personal computer vendors have used marketing and distribution outlets such as Radio Shack and Computer Land to reach the individual retail market. It was a departure from tradition, for example, when IBM announced in 1981 that it would use Sears and Computer Land as outlets for its first home computers.

A second departure from computer companies' traditional practice occurs in the software or programming market. The computer companies of the 1950's to 1970's tried to make their equipment customers captive to the software that the companies developed and sold. Independent software companies had difficulty staying afloat in the software market; they suffered financial setbacks when computer companies made minor unannounced changes in their operating systems. This is not a feature of the personal computer market. Programs are written by many sources and are advertised in the trade press or in company documentation. A diversity of applications programs has resulted. Computer vendors still usually supply at least one operating system and one programming language as part of their basic system.

The owner of a personal computer is in the position of selecting programs from a catalog. I looked through lists of programs advertised and found such entries as:

Your personal financial management system	$50
Your spelling aid	$250
Accounts receivable system	$600
Handling your time—for lawyers	$400
Playing chess	$600
Household management system	$75
Home security checking system	$300

With each entry there was a short description including the compiler or operating system used, programming language, number of bytes of memory needed in permanent storage and on disks, display or printer used, supplier or individual programmer, and computers on which the program runs. The programmer receives royalties, the software supplier makes a profit, and the buyer obtains bargain programs with yet-to-be-determined reliability and no guarantee of satisfaction.

Thus the entrepreneurial mode characterizes the smart electronics market in both equipment and software design and application. However, a study reported in 1981 (*11*) concludes that this market structure is a transient phenomenon and that in a few years there will be only seven to ten major personal computer suppliers worldwide. Whatever happens, the individual will be the benefactor of a great technological advance, steadily decreasing costs for products and services, and a mixing of computer technology with other new consumer technologies.

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