Chapter 3
Information Systems and Computers

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The Nature of Computer-Based Information Systems

Traditionally, the popular view of computers has been that they are super calculators that automate processes which were previously performed by numbers of people sitting at mechanical adding machines. However, computers carry out a wide variety of tasks associated with processing information. It is important to understand the entire range of these capabilities in order to appreciate the nature and magnitude of the potential social impacts of this technology when used in information systems.

Computer capabilities fall into seven main categories:

1. *Data collection.* When attached to various sensing devices, computers can detect and measure such external physical phenomena as temperature, time, pressure, flow rate, consumption rate, or any number of other variables. Also, computers can keep a record of transactions. For example, a computerized cash register can collect and store information about a sale that includes bookkeeping entries, taxes, commissions and inventory, and can even reorder stock. Some computer-based door locks require individuals to carry magnetic identity cards. Such locks not only can control access but also can create a record of whose card was granted access, when, and for how long.

   Technological advances are beginning to provide computers with the capability to directly process visual and audio input, thus greatly increasing their applicability to data collection. Computers already have a limited ability to recognize human speech, to read directly a variety of typewritten forms and handprinted texts, and to detect patterns in video images. These functions will be improving rapidly over the next decade and will appear in commercial equipment.
2. *Information storage.* Computers can store large amounts of information for long periods of time in an electronic-readable form that is easily and quickly recoverable. Depending on the particular application, the methods of storage vary widely, from signals in electronic circuitry, to magnetic pulses on tape, to holes in cards. New advances in memory technology eventually will allow trillions of characters of information to be stored conveniently and cheaply wherever there is even a small computer. The cost of storing information electronically will soon be substantially lower than the cost of storing the same amount of information on paper.
3. *Information organization.* Computers can be used to rearrange information so that it is more suitable for particular applications. For example, if the data in a telephone directory were stored in a computer's memory, it could be inverted to allow one to look up a telephone number that corresponds to a particular address. More generally, computers can simplify and restructure vast amounts of raw data to assist people in drawing significant meanings or conclusions.
4. *Calculations.* Computers perform arithmetic calculations millions of times faster than can human beings. They are used to make numerous simple calculations, such as those required in processing the payroll for a sizable organization; to make sophisticated statistical calculations on large amounts of data,

such as those for social science research; or to perform highly complex scientific calculations, such as those needed for weather research or for modeling fusion energy systems.

5. *Communication.* Through connections over a telecommunication system, computers can transmit data around the Nation and the world either to human users or to other computers, which permits the sharing of work and data among groups of linked computers (known as computer networking). Private firms are beginning to offer special communication services to support computer networking. In addition, computers make possible the more effective use and management of the communication systems themselves.
6. *Information presentation.* Computers can put out information in a variety of forms. Through graphical display, and more recently through voice response, they can make data readily understandable and useful to nonexperts. It is possible to have data and computer schematics displayed on screens in a multicolored, three-dimensional format for design and analytical purposes. Also, data such as numbers and statistics can be organized by the computer in an easy-to-understand tabular presentation. Much of the programing effort in developing modern management information systems is directed toward designing ways in which the information generated by the computer can be presented most clearly to the manager who needs it.
7. *Control.* Computers can be used to control a machine tool or a production line without human intervention. Many consumer devices—including microwave ovens, automated home thermostats, automobile engines, television sets, and telephones—incorporate computer controls using new microprocessor technology. Such uses are increasing rapidly.

Several of these capabilities can be combined, for example in *computer-aided design* of aircraft structures (or computer logic elements, for that matter) and *computer-based modeling* of the saltwater penetration in San Francisco Bay (a function of tidal action and ground water runoff). Both computer-aided design and computer modeling are finding wide application and are illustrative of what is sometimes referred to as the "intelligence amplifying" capability of computers.

History of Computer Use

Over the last 30 years, computer systems have evolved through stages that emphasized particular capabilities and that have altered the way society handles information. The nature of these applications has been shaped, in part, by the available technology, but also by the changing perception of computers and how they may be used most effectively.

Few applications were new, however, at least in the beginning. Society has kept records and exchanged information for centuries. It is important to understand this background, since many computer impacts, both beneficial and adverse, arise from the changes in historical information practices that occur when computer systems are substituted for manual systems.

Some significant trends in the development of computer applications are discussed below:

Computer trends in the 1950's: Increased size and centralization.

In the 1950's, every announcement of a new, larger computer elicited the comment that only a few would be needed to serve the computer needs of the entire country. "Grosch's Law"-an empirical estimate that one could get four times the computing pow-

er at twice the cost—provided an economy-of-scale rationale for large, centralized systems.

This underlying economic rationale forced organizations to pool their computing applications in central computer centers that would run them on as large a machine as possible. This operating style, which can still be seen in many organizations, had two principal drawbacks.

One effect, seen immediately, was that centralization separated the users from the computer forcing them to gain access to the machine through layers of bureaucracy. Some applications were not harmed in such an environment. However, delays and bureaucratic costs inhibited the work of such users as scientists, engineers, and students. They often could not perform the type of creative work that the computer was expected to foster.

The second effect was more subtle. Economy-of-scale no doubt existed technologically—multiplying two numbers was cheaper on a larger machine. However, designers had to generalize the computer hardware and programs in order to handle all of the different types of applications that had been pooled to justify the big machines. Thus, preparing a payroll, performing small engineering computations, and calculating a very complicated mathematical model, all might be handled by the same computer. Some of the theoretical efficiency gain for a large general-purpose computer was lost in the system overhead required to provide the facility for such a variety of applications.

Despite these drawbacks, computer use grew rapidly during this period. Most applications concentrated on using computers both as calculators and as controllers of large (for that time) record systems, usually kept on magnetic tapes or punched cards.

Computer trends in the 1960's: The minicomputer and timesharing.

In the 1960's, motivated by the two above-mentioned drawbacks, users on university campuses and in research laboratories developed two design concepts that fundamentally altered the way in which computers would be used—the minicomputer and timesharing.

In the early years, many scientists learned about using computers by sitting at them and programing them directly. Chafing at the bureaucratic and physical barriers being erected around the central system, these users developed small, specialized laboratory computers which, although not cheap by current standards, were far less expensive than the centralized systems that often cost in excess of a million dollars. These small machines, or minicomputers, were cheap enough so that a person sitting and working at one could afford to use it at less than optimum efficiency. The loss of machine efficiency was offset by the increase in human efficiency.

The other important concept, "timesharing," was developed because a large system cost hundreds of dollars per minute to operate. Thus, an individual could not engage in a rewarding working session sitting directly at a large computer, which was dedicated to that user, without enormous waste. Humans work slowly compared with computers. Consequently, the computer would be idle most of the time while waiting for its user to initiate some action.

Timesharing was designed to make that kind of direct use efficient by enabling a computer to serve many users simultaneously. With such a system, each user sits at a terminal. The computer transfers its attention rapidly from one user to another, performing work as needed. Information is processed so quickly that the computer, in effect, appears to be totally dedicated to the work of each user.

Once the concept of timesharing had been incorporated, it became apparent that users did not have to be in the same room as the machine, but could communicate with it over communication lines from across the country or from anyplace in the world.

Thus, although large centralized systems continued to grow for applications such as recordkeeping and laborious computations for scientific research, the groundwork was laid in the 1960's for new types of computer use and new ways of designing systems to meet specific goals.

Computer trends in the 1970's: Communication-based computer systems and networks.

In the 1970's, communication-based computer systems began to grow. Some types of recordkeeping applications were obviously handled best by large central computers, but to be useful they needed immediate data entry and retrieval of information from remote locations.

Airline reservation systems, for example, were among the first large communication-based computer systems to be developed in the commercial sector. Reserving airline seats is clearly a complicated task, well--suited to computerization. Agents all over the country can now check flight availability and reserve seats from their work stations, both in "real time. " (This term is used by technologists to refer to applications in which immediate action and response is provided by the computer.)

Another example of a large communication-based centralized computer system with decentralized access is the one operated by the National Association of Securities Dealers (NASD), known as NASDAQ (NASD Automatic Quotation.) It allows securities dealers instant access from their desks to the latest bid and ask prices for any stock listed on the over-the-counter market. The need here was clear for real time access to a data base by dealers across the country.

Another trend in the 1970's was the linking together of multiple computer systems—both small and large ones—into "networks." ARPANET, a project of the Department of Defense's Advanced Research Projects Agency (ARPA), was an ambitious and technically sophisticated experiment that linked together several large ARPA research computers over high-speed communication lines. This project was based on a new technique, called "packet switching, " that allowed existing communication lines to be shared more efficiently for carrying computer data.

Future Trends in Computer-Based Information Systems

Three dominant economic factors can limit the range of computer applications:

1. the overall cost of computer hardware and the associated economies of scale;
2. the cost and difficulty of setting up and maintaining high-speed data communication links; and
3. the cost of producing software–the programs required to operate the system.

The first two limitations are being overcome. While there is still a strong market for large expensive systems, the cost of computing hardware has dropped to the point where, for many applications, possible economies of scale are offset by the overhead costs and the inconvenience of a large system. This trend is leading to the reliance on multiple smaller systems that are distributed geographically.

Several companies, American Telephone & Telegraph and Satellite Business Systems, for example, are building commercial data communication networks that promise to be economic, efficient, and convenient to use for linking together data systems and users.

The remaining problem, the cost of the software, is the pacesetting factor.[1] Progress has been slow in the development of new cost-cutting techniques for programing applications. For many applications serving a sizable user market, programing costs can be written off over a much larger user base. However, for a number of large specialized applications, the programing, maintenance, and operation costs will continue to be the dominant factors in the cost of using computers. Some experts see the software problem as the major obstacle to new applications of computers. For at least the first half of the 1980's, the cost of competent, sophisticated programing efforts will limit progress.

Based on the findings of this study, the use of computers will likely follow these trends in the 1980's.

- Growth *in the use of personal computers.* The small computer will become common both in the home and in business. Despite their small size, these systems will be highly capable–the equivalent of machines that sold for as much as $1 million in the 1950's. They may appear in the guise of video games, television sets, or telephones that will also have a computer capability available for other purposes. This trend will stimulate more widespread computer literacy in society, and in turn be reinforced by the consequent increase in the number of people able to program and use computers. The first generation to grow up with computers is now reaching maturity. These "computer literate" young adults accept computers as a natural part of their world. Computer design and use will be taught increasingly in school and as part of adult education, and will enhance an already thriving market for specialized application programs designed for small computers.
- *Expansion in the number and size of computer networks.* By the end of the decade, most computers, even small *ones,* will be connected to a communication network at least part of the time.

  The communication system may be dedicated to a single application in which all the machines on the network perform portions of a larger task. Public data networks, on the other hand, provide any home or business computer with access to a wide range of data bases or special programs that may be wanted for occasional use. Such multiuser national networks that can be interconnected now exist, and the number of users is expected to grow at a rapid rate.
- *The trend toward information services.* The computer industry has traditionally been concerned with selling hardware (desktop, mini, and mainframe computers and related auxiliary equipment). However, current trends in both pricing and the structure of the market are driving the emphasis toward providing computer-based information services, such as bibliographic and data base searches, electronic publishing, electronic banking, and the like. A number of these services will still require that the user possess a computer. However, many will be offered over data communication lines to homes and offices, and will be accessible through a modified ("intelligent") telephone or television set. Examples include two-way cable television, videotext, and the AT&T Electronic Information Services experiment that provides an electronic telephone directory over a telephone line to a home terminal. Eventually, information services of all kinds will dominate the data processing market in terms of dollar volume. (See ch. 14 for a detailed discussion.)
- *The competition among giant corporations for the data communication services market.* IBM, AT&T, Exxon, and GTE, among others, are preparing to offer a variety of data communication services.

[1] "Missing Computer Software, " *Business Week,* Sept. 1, 1980, pp. 46-53.

Large corporations such as these have access to the capital required to install the technological base for the planned services, such as communication satellite systems and fiber optic transmission lines. A series of recent rulings by FCC, some still under challenge, are intended to clear the way for open competition among these and other corporations to provide information services of all kinds over communication lines. Resolution of the pending challenges by the courts or by Congress will have significant implications over the long term for the data communication industry. (See the OTA telecommunication study for a detailed discussion.[2])

At the same time, an examination of the computer industry (see ch. 14) shows that small entrepreneurs have frequently been innovators. This observation in no way discredits the valuable fundamental advances and product innovations originating from the research laboratories of large firms such as AT&T and IBM. However, creative new systems and innovative services increasingly arise from small, new, "spin-off" enterprises or from totally new entrants into the market.

Thus, faced with the dominance of the data communication field by large corporations, others in the information industry will press for a public policy that will guarantee access to data communication networks by smaller firms and new entrants that offer information services.

- *Higher level integration of data services.* Many individual networks for servicing specific corporate and governmental needs will continue to be built. Some of these networks will become integrated. For example, most airlines, car rental agencies, and large hotel chains have their own reservation systems. It is now technically feasible to build an integrated system that would provide travel agents access to all of these reservation systems through one desktop terminal.

  Similar integrated information systems are also feasible in insurance, banking, travel, entertainment, law enforcement, commodities exchanges, medical services, and many other sectors that now use several separate information systems. There are a number of factors such as system incompatibility, antitrust considerations, or competitive problems that may tend to resist this integration in the case of some systems.

- *The software bottleneck.* According to many computer and industry experts, the increasing capability of computer hardware is not being fully utilized due to problems encountered in creating suitable software programs for these new machines.[3] The major problems are the relatively slow increase in the productivity of programers-their cost efficiency–compared with that of the hardware, and the difficulties encountered in managing large programing projects.

  These problems have created bottlenecks in the development of new applications. Computer programing has been relatively resistant to productivity improvement, at least when compared with corresponding improvements in hardware performance. Programing is by nature labor intensive. Its cost is rising due to the increased programing requirements of new hardware coupled with a shortage of programing personnel with the needed training and experience. New mechanisms such as structured programing will be helpful in engineering computer programs and for managing their design and implementation.[4]

  At the other end of the scale, microtechnology is making possible enormous in-

[2]U.S. Congress, Office of Technology Assessment, *Telecommunication Technology and Public Policy Issues,* in press.

[3]Computer and Business Equipment Manufacturers Association, *Industry Forecast Panel: Productivity, 1980* spring meeting.

[4]Some progress in improving software has been made by use of structured programing methods such as FORTH. See John S. James, "What is FORTH? A Tutorial Introduction, " Byte magazine, August 1980, pp. 100ff.

creases in computational power through the creation of new hardware structures from clusters of small computer chips. Technologists know how to physically construct such combinations, but not how to use them as effectively as their potential would suggest.

Eliminating software bottlenecks may be the key to maintaining the lead in computer technology in the coming decade. In Japan, for example, the software problem has now been given a very high priority for R&D. In the United States, although a few defense agencies are investing in research to solve some of the problems, Federal R&D budgets for computer science and technology have not accorded software a similar priority. Private industry is the source of most activity in this area. Reportedly, one-third of the research effort at Bell Labs is devoted to the software problem.