The technology on which microcomputers and allied developments are based is rapidly progressing, but the extent and directions in which development continues will be determined largely by social, not autonomously technical, factors. This technology can, within the next decade or two, advance to the point where an enormous range of new applications will be economically practicable. A wide variety of microcomputer applications are already underway in computation, automation, data management, and communication. This article surveys some of the more important of these, and suggests the vast social implications which they have. The applications themselves and their effects are, it is argued, at least partially subject to social control. The article suggests some of the blocks on further innovation, and some of the social choices to be faced.

The Microcomputer Revolution?

Technical Possibilities and Social Choices

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Microcomputers are the tip of a technological iceberg—the innocent-appearing indicator of a major underlying technology whose contours and implications we can only vaguely grasp. It is easy and true to say that microcomputers can do very little that earlier information processors could not already do. Indeed, there are still a great many important tasks which are well beyond the computational, and especially the memory capacities, of microcomputers. There probably always will be. Nonetheless, microcomputers are already exerting profound influence on industry, government, health care, education, the military, and numerous other sectors of society. Their impact is as great on management as on workers. And their importance will grow. Microcomputer technology is still in the early stages of development—recognition of its potential and strategies for making effective use of it, are lagging behind the hardware.[1]

What makes microcomputers distinctive and important is not the upper limits of what they can do. The influence of the microcomputer is due, rather, to its cheapness, small size, energy efficiency, and reliability. Moreover, the underlying technology sup-

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ports not just the highly visible microcomputer, but scores of other devices of potentially enormous impact. In fact, we have reached a point where quantitative changes in technological capacity may, if they are fully enough exploited, have a qualitative impact on social life.

TECHNOLOGY

BACKGROUND

The first significant computers were built during World War II. Their memories were not large enough for much else than crunching through large computations and cracking codes. They grew through the 1950s, but computers were not widespread until the invention of transistors enabled them to escape the limits of size, reliability, and the special working conditions (e.g., air conditioning) imposed by the use of tubes. This breakthrough came in the early 1960s. Computers themselves, in other words, are only a very recent technology.

The computer industry is a very dynamic one. In the United States it sold some $30 billion worth of its wares in 1980, and is growing by as much as 15% per year. With microprocessors on its leading edge, the computer industry looks poised to become the world's most important (Evans, 1980: 89-90). The annual semiconductor market is now perhaps $10 billion; the leading supplier, Texas Instruments, predicts it will reach $32 billion by the late 1980s.[2]

The scale and rapidity of microprocessor development and innovation may be somewhat difficult to grasp. The first microcomputer was sold in 1974, as a kit for hobbyists, by a tiny New Mexico company. The firm was nearly bankrupt when it marketed its kits, and needed to sell 800 during 1975 to satisfy its immediate financial obligations. It sold some 2000—all that it could manufacture—and continued to expand until it was bought by a larger company in May 1977, for some $6 million worth of stock (Osborne, 1979: 28-29).[3] Today, the microcomputer and personal computing industry is doing more than a billion dollars of business a year in the United States, and growing exponentially (Economist, Nov. 8, 1980: 93).[4] The 1974 microcomputer was based on an Intel 8080A microprocessor; today's leading sellers are ten times faster and two to four times more powerful. Early in 1981, if all goes according to plan, Intel will begin deliveries on the 8800. This first mass-produced 32-bit microprocessor will have the same word length capacity as some contemporary mainframes. This will mean that in less than ten years, the microprocessor industry will have gone through four generations, seen its power by eight times, and its speed by considerably more than that.

Microprocessors are built today on silicon chips approximately a centimeter square, usually housed in plastic or ceramic holders with metal switching contacts to produce what is called a Dual In-Line Package (DIP). Chips cost about three dollars each in the most popular models, though Intel's 8800 will cost over $1000 at first. Everyday chips can outperform 100,000 transistors. They are entirely adequate to transfer virtually all processing functions from traditional mainframes to microcomputers. The holdup is memory.[5] Floppy discs, which enable the "stylus" to jump tracks in order to rapidly access any bit of information, are still very expensive. A bottleneck developed in which there were few manufacturers—and only one major supplier—due to unanticipated demand. The larger discs are not, in any case, usable on present-day microcomputers. In addition, printing costs are still very high for discs, making it uneconomical for most users to acquire their own data libraries. Experiments are being made in the development of "bubble-memories" and other dramatically new technology, but these are not yet widely applied. For the time being, advance will be linear, and no one is quite sure how serious the limits that it will run up against will be (for a fairly conservative discussion see Noyce, 1979).

MEMORY AND POWER

There are two ways of increasing memory by improvement of existing technology. One is to etch ever finer patterns on chips; the other is to increase the size of the chips. Progress is being made on both fronts, but stumbling blocks are numerous. At present, the lines etched on chips average about 2-1/2 microns. For every ten-fold decrease in line-width, there is a hundred-fold increase in the number of circuits the chip can hold. The ultimate limits here are optical, and are speculated to be about 0.3 micron; in practice, achieving one micron widths would be a major advance, and is not expected in the immediate future. Manufacturers are already having quality control difficulties with the etching of 2-1/2 micron lines. Increases in chip size are dependent on reducing defect densities in fabrication. Noyce (1979: 333-334) predicts continuing increases here, but as with line-width, quality control problems are considerable.

Manufacturers are at present producing mainly 8k and 16k dynamic rams—that is, chips with 8,000 or 16,000 units of random access memory. This is considerable progress from the 4k units of the early 1970s. Indeed, 64k rams are on the market, but in limited quantities. Some Japanese companies seem to be on the verge of putting 256,000 memory cells on individual chips, though these will not be available as products for a few years.

The block is really economic, not technological in nature. Manufacturers of chips generally do not examine their products after manufacture, since they cannot readily be repaired, but rather simply test them and throw away those that fail to function. This is nice for the buyers, who get very reliable products, but it creates a considerable problem for manufacturers. Testing, for one thing, can take as long as two days for a very densely packed chip. That still leaves a problem of yield—the percentage of good chips in the batch. This is much higher with the tried and true methods of producing 16k rams than it is for the 64k versions. Since market demand is at present much higher than production, companies are loath to risk the lower yield, "up-market" products.

This difficulty is compounded by the fact that capital costs for developing and producing the new chips are rapidly rising, and the companies have often gone after volume to the neglect of profits, resulting in a shortage of operating capital. The 64k chips are not certain to find the mass markets which the 16k and smaller memory chips have commanded. So, technological advance may finally stop moving at breakneck speed. It appears that it will have to wait for innovators to catch up. And, as we shall see in a later section, innovations face many more social problems where microcomputers needing 64k+ RAMS are concerned, than wristwatches requiring a negligible memory.

Nonetheless, the 32-bit microprocessor and the chip with between 64,000 and 256,000 random access memory cells are on their way if we want them. Access times as low as 100 nanoseconds or better are the norm, and the cost is already well under one cent per unit of memory and rapidly falling. The core of much more advanced microcomputers will be with us thanks to very large scale integration of circuits. The major limits to advance are thus social and economic, not technological. Major new applications for microprocessors must be developed if the production of these is to take place. Society has thus more power to determine the implications of the technological advances than might at first be thought.

SPEED

An important area for potential improvements in basic semiconductor technology is speed of processing. Here the silicon basis of chip technology is itself a major limit. The only way to increase speed within this technology is, as with memory, to etch ever tinier and finer lines on the silicon. Not surprisingly, this is difficult and expensive. Nonetheless, the Defense Department seems to be urging manufacturers to take on the challenge of getting circuit-lines down to one-half a micron in width (Economist, Jan. 12, 1980). The processors which this would produce are called simply "very high speed integrated circuits." A catch to hopes in this area is that neither the engineers nor the skilled fabrication workers needed are in abundant supply, and the infusion of Pentagon money, however welcome, is likely to overtax available production resources. Since commercial products are already in high demand, this is likely to drive up the price and introduce supply delays. Thus, one of the major advantages of microprocessor technology would be endangered, and at the same time the U.S. edge on the international market would be undercut by opening a much larger section to already active Japanese competitors (and potentially to Europeans, though their technology is still lagging).

A further problem with the ever-smaller silicon circuits is that they generate enough heat to impair their own functioning and, indeed, cause errors in computation. Backup processing capacity which would take over in case of self-diagnosed problems is one solution, but of course, it only makes the processors more complex, and thus more expensive and difficult to program. Another development has been the "Josephson junction," which can switch very fast—perhaps seven trillionths of a second, and generate much less heat. However, Josephson junctions are difficult and expensive to make; even more problematical, they must be operated at temperatures very close to absolute zero and are quite fragile.

More promising for the short-term future are two other technologies: optical computers and distributed array processing. The first is still quite a distant possibility, but not necessarily an impractical one. Basically, an optical computer would use a laser beam to make binary switches as rapidly as one trillionth of a second each. The new technique is based on discoveries by Britain's Stanley Smith, who calls the projected device a "transphasor." The other, and somewhat further developed new technique is distributed array processing. Here it is not switching speed itself which is improved, but the overall efficiency of the processor. Instead of separating memory and computational functions, DAPs rearrange the architecture of the chip so that thousands of processing functions take place in parallel. The savings is the time spent by conventional processors in transmitting messages between memory and computational components.

By the 1990s the silicon chip may finally be facing gradual obsolescence rather than continual improvement. In addition to the optical "transphasor," gallium arsenide chips are a serious contender. Their disadvantage is that unlike cheap and abundant silicon, gallium arsenide is expensive. Nonetheless, it can increase electron speed by as much as 30% (though due to fabrication difficulties, pathways will have to be somewhat longer than in silicon chips, thus reducing the overall gain in switching speed). Unlike some of the other possible new technologies, however, gallium arsenide chips could be made with largely similar equipment to that used today with silicon. Computers presently incorporating silicon chips would not have to be redesigned to use gallium arsenide replacements. Doubtless other new technologies will be suggested before the 1990s are upon us. Choices will have to somehow be made among a wide range of technical possibilities.

OPTICAL DISPLAY

A frequently neglected stumbling block for the often announced triumphant advance of microcomputers into all areas of information use is display technology. Advances in optics have not occurred with quite the rapidity of those in electronics, and as a result, the cathode-ray tube is still the primary display technology. Microcomputers are either fitted with their own or hooked up to television sets. This impedes satisfactory miniaturization of display, and ought to give pause to those predicting that printed reading matter will have all but disappeared by the end of the century. The present technology simply does not provide a pleasant enough representation for extended periods of reading, and can, with over-intensive use, harm the eyes. Cathode-ray tubes are also relatively fragile and unreliable (by comparison to the rest of microprocessor technology), and they use a good deal of energy.

Recent work in optics shows signs of producing alternatives. Perhaps the most likely are various uses of liquid crystal. The obvious technique is simply an extension of liquid crystal displays (LCDs) which are used in digital watches and similar applications.

This involves problem in achievable speed and size, however, though it is highly energy efficient. Nonetheless, by the end of the century, liquid crystal screen displays should be practical.

These displays may, however, go further and depend on liquid crystal memories. Here, the technique is to use several tiny lasers to print a miniature image of computer data on a liquid crystal. There it is stored until needed, at which point it is displayed by projecting an enlarged vision on a solid screen. This technique is already in the experimental stages, and offers several advantages. First, the image is free of television screen flicker. Second, an LCD measuring just 18 millimeters square can hold up to 33,000 characters of information. Third, information can be rapidly and easily updated: The whole display can be rewritten in under 12 seconds. Partial images may be readily and more quickly revised. Fourth, though a recorded image should, under appropriate operating conditions, be retained by the crystal indefinitely, it can be erased if necessary. A radio beam combined with heat from the lasers can erase even a tiny area specifically requiring updating. The system is based, like other up-and-coming microcomputer technologies, on gallium arsenide. Here gallium arsenide lasers change the alignment of the crystal structure wherever they hit it, producing black spots on the front of the crystal when light is reflected through it. Color displays are possible, but difficult. The crystal memory display is likely to be on the market (at undetermined price) by about 1985, if IBM's plans are successful.[6]

SOUND

Sound synthesis and comprehension might be considered more applications of microprocessors than allied technologies, but they are, in any case, important conditions of some other applications. Texas Instruments predicts a $3 billion-a-year market by the end of the decade for micro-processors capable of recognizing or producing speech. Already various minor applications are taking place using the new technology.

Speech synthesis is much more advanced than speech comprehension. Basically, a processor embodies a mathematical representation of a variety of sounds, including, if desired, whole words. When called upon, the synthesis chip sends the digital summary of a statement to loudspeakers via a decoder and amplifier. Of course, the same techniques can be applied to music as to human speech. Digital recordings are already in fairly widespread use. Their major advantage is that they eliminate the various defects of master tape recordings, which reproduce an analog rather than an exact digital representation. The electronically memorized pattern can also be much more satisfactorily stored and transferred to additional recordings than can the tape. At present, sound synthesis technology offers a significant trade-off between quality of reproduction and price. The common computer-synthesized voices one hears—in children's toys, for example—lack richness. This is because a good deal of the array of tonalities and modulations of the human voice is left out in order to store more speech on a single chip. Here again, memory is the major stumbling block; accurate reproduction of human voices is quite possible, but takes several times the memory of computerspeak.

Voice recognition and comprehension are much harder to produce. At present, minicomputers are still struggling to recognize more than a hundred words and cost between $10,000 and $20,000. Satisfactorily reducing the technology to the dimensions of chips is still in the offing, though, as capacities increase. Even with the larger computers, accuracy is a problem. IBM's 370-168 has so far only been programmed to recognize its vocabulary of 1000 words with a little over 90% accuracy, even among speakers it is used to. The computers have a great deal of difficulty adjusting to different voices and accents. The major applications pushing the technology forward are industrial. In some jobs, workers need to have both hands free, and yet be able to communicate—say, to record data. An example comes from within the microelectronics industry itself, where quality control workers must check tiny integrated circuits under microscopes and the keeping of hand-written records is a major slow-down.

Further progress may depend on the development of better and cheaper digital/analog converters. This technology is not limited to sound production/reproduction, but is integral to most of the computer's avenues for contact with the real world. Sensors or transducers are adequate in neither quality nor quantity. They have proven very hard to reduce to chip size. By recent reports, however, major firms are now beginning to invest considerable sums in this area. There are basically three varieties of converters: successive approximation devices, which try a number of possible translations until they reach a satisfactory one; integrating devices, which draw information from all possible data points and assemble a single answer; and parallel array converters which "sample" the available data (see discussion in the next paragraph). The three are listed in order of ascending cost, but the latter two are vastly more accurate, with the integrating converter being the best on this score, but rather slow. The parallel converter has the overwhelming edge, being several times faster than either of the others. All three varieties are potentially convertible into practical chip designs, but at present the last seems to be making the running.

VISION

It is in the field of vision that digital/analog conversion finds its most difficult challenges, and it is here that the parallel array processor really shines. Instead of running through an immense sequence of individual binary decisions to identify relevant information, the parallel array processor is able to process the whole array of individual units of information—dots in the case of vision—simultaneously, and select the most relevant from among them and concentrate its attention on this sample. It does this by identifying discontinuities—edges—which define distinct images. Of course, the speed of the processor is valuable in itself as well as part of this "sampling" process. Advances in speed of processing visual information are crucial, however, to one of the most important applications of microprocessors—robotics. Though advances in robot automation are constantly taking place, the field is still held back by problems in both the sensors themselves and in digital/analog converters. The parallel array processor may shift the bottleneck from hardware to software, as programmers struggle with the highly complex programs necessary to take account subtle environmental changes (such as in lighting), as well as to accomplish the basic tasks. Some sensor difficulties still remain to be solved before robotics can further increase the demand for microprocessors.

TECHNOLOGICAL DETERMINISM, CAPITALISM AND SOCIAL FACTORS

Popular books and articles on microprocessing tend to suggest that this technology either "just happens" as a part of the inexorable rush of progress, or else is the result of one of the last pockets of exciting, free entrepreneurial capitalism. Both accounts leave a good deal out. The first rather neglects (1) the considerable importance of financial backing to achieving technological advances, and (2) the fact that choices among possible routes of technological progress are constantly being made.

The entrepreneurial explanation underestimates the importance of social factors in producing the demand which allows some entrepreneurs to survive, as well as the importance of government provision of education, and other such prerequisities. It also tends to treat all microprocessors and all markets as the same. This means that the difference between producing and marketing a digital wristwatch or child's game, and doing the same for large capacity business computers is neglected. Such neglect inhibits the capacity of the entrepreneurial explanation to account for the more advanced microprocessing technologies and applications—the ones which are increasing in proportionate importance. Its proponents conceive of the microprocessing market as dominated by tiny, entrepreneurial firms. This was never entirely the case, and is less the case now. The leading American producers of microprocessors are all established, large corporations—in order of 1978 volume, Texas Instruments, National Semiconductor, Motorola, Intel, Fairchild, and so forth.[7] Not all of these are even specialists in computational equipment.

The technological determinist and entrepreneurial explanations are put in even greater doubt by the growing influence of government subsidies to the development of microelectronic technologies. Japan is currently causing considerable anxiety among American producers by introducing chips of greater capacity and more exacting specifications and quality control. At present, the market is so elastic that supply is more of a problem than demand, but the long-term future of technological development is at issue, not just corporate fortunes. The Japanese government has not only subsidized the production, but it has allowed the companies to operate with extraordinary debt/equity ratios—an industry average of 345% compared to 16% in America (The Economist, Feb. 23, 1980: 86). Intraindustry cooperation has also been crucial in Japan.[8] In Britain, a joint government private venture called Inmos has been set up to promote the microelectronics industry—and it's favored by the Tory government![9] It also has imitators abroad, as far afield as South Korea. Underdeveloped countries such as Ireland, and underdeveloped states such as North Carolina, are also giving less direct, but no less real, subsidies as incentives to attract the seemingly desirable microelectronics firms to their soil and their unemployed workforces.

These various flaws in both technological determinist and entrepreneurial explanations mean that if we want to estimate the future for microprocessor-based innovations, we must understand the impact of various social forces and obstacles. We must get away from the tendency to treat social variables entirely as "implications" or "effects" of technological change.

The process and probability of technological innovation cannot be adequately understood in isolation from the possible applications of that technology, and the market incentives or other pressures which potential users can bring to bear on producers. While admitting that, with certain fairly inexpensive and potentially mass-market items, markets can be more or less artifically created for new products—for example, with electronic games—I suggest that the most significant of applications will exert a prior influence on product design. The technological potential of microelectronics is extremely great; selections will be made among technological possibilities. We cannot validly interpret any coming "microcomputer revolution" as simply caused by technological advance.

APPLICATIONS

Applications of microprocessor technology are extraordinarily wide ranging. What I shall do in this section is indicate several of the major functional areas in which microprocessors may be used, including under each heading examples of current applications, possibilities for future applications, social implications, and blocks in the way of innovation. The functional areas to be considered are computations, data management, communications, and automation. Obviously, as will become apparent, several particular tasks to be performed by microprocessors will overlap these categories.

COMPUTATIONS

The traditional domain of electronic data processing is becoming an ever smaller part of its job. The reason for this is not primarily a slackening in demand. There are more calculations and computations to be made in the world today than ever before. They are a smaller part of the task of today's computer technology because they can be done extremely rapidly, and because computers can do other things as well—indeed, they can do other things primarily by reducing them to calculations and computations. Nonetheless, there are new applications being made and still to be made in this area. Before we go on to them, a few comments about large computations are in order.

Memory shortages often keep microcomputers from efficiently handling computations involving large data bases. A prime example of this is electronic funds transfers among banks. Millions of checks are processed every day by computer, at ever smaller unit costs. Indeed, this is a large part of the reason for the progressive disappearance of the distinction between checking and savings accounts. The costs of processing checks have fallen to the point where it is worth more to the banks (and savings and loan associations) to compete for funds by offering interest on checking accounts.

Credit card charges are now also processed extremely rapidly and in large volume due to improved computer technology. While memory shortages are likely to keep microcomputers out of the main part of this business for some time to come, there are a number of subsidiary tasks which they can perform. Microprocessors, for example, are integral to "reading" the numbers printed in computer code on modern checks—and for that matter on modern groceries. Microcomputers may, in the fairly near future, be able to perform more complex and thief-proof checks on the identity and authority of credit card users.

Perhaps, at least as importantly, microelectronic devices, though not microcomputers, are becoming internally important to large-memory computers. The technology involved in this is the "bit-slice," which is, in essence, a single chip divided into several parts, each of which can be programmed to perform a distinct function. Current 8-bit slices can handle words as long as 64 bits, and thus work with great speed and accuracy. They are instrumental in greatly improving the memory and other functions of large computers, in which one bit-slice may take over a set of fairly simple functions previously performed by individual chips.

Almost as important a reason as memory for the continued prominence of large computers is large programs. Some of today's programs are truly gigantic, for example, in military applications such as tracking systems for the Strategic Air Command, and in some banking and financial applications where numerous contingencies must be accounted for. These programs raise a number of problems of their own, such as the difficulty of tracing the source of high-technology embezzlements in electronic funds transfer systems. Less spectacularly, they are very difficult to ever completely debug, and the complexity of their construction produces problems for systems designers needing to organize and allocate responsibility among large teams of programmers.[10]

Microprocessors are not likely to be able to deal with extremely large programs at any time in the near future. Indeed, there is likely to be something of a polarization in hardware production, perhaps eliminating what are currently called "mini-computers." More and more of the functions of the latter are likely to be taken over by microcomputers; mainframes will grow ever larger as they are needed only for extremely large or complex functions. Microcomputers may, however, be a part of reducing the complexity of the human tasks involved in the construction of large-scale programs, as they may take over some of the programmer's role (on these and related possible developments, see Perlis, 1979).

The responsiveness, portability, and economy of microcomputers fits them well for certain kinds of computational applications. In weapons design, for example, while economy is not, perhaps, a major issue, portability takes its place, and responsiveness is usually crucial. Modern airplanes and tanks, and even some experimental hand-held weapons, are able (1) to give their users instant information on a variety of their own operations or environmental conditions, and (2) to take over on a variety of functions—such as target finding—in which both speed and accuracy are of the essence. Microcomputers have the additional advantage that they function fairly reliably in hostile environments, and that they may be more readily sacrificed than human lives. In any case, "microelectronics capability is the key to modern military power" (Barron and Curnow, 1979: 122). It is, further, not so easy to control as many military technologies.

The greatest increase in interactive computing probably does come from the personal computer. This is, of course, a vague designation, since the sort of computers which were primarily sold to hobbyists five years ago are now frequently used in business settings. In any case, though there are a variety of other uses for personal computers, computations as such are in the forefront. Scientists using microcomputers are able to do almost all the calculations for which they would otherwise use mainframes; only large data sets send them back to central data processing facilities. A ready possibility for personal computation use is in income tax preparation. A major advantage individuals gain is a check of all possible options, i.e., for income exclusions or deductions, by which they might legitimately reduce the amount of tax payed. The computer can easily run through all the possibilities, checking first the individual's eligibility, and then computing the gain, if any.

Early marketing of personal computers, and early predictions of the "microcomputer revolution," had home users primarily in mind. For various reasons, including continuing programming difficulties, cost, and lack of understanding of computers on the part of most of the population, the home computer market has not taken off as fast as expected.[11] The use of microcomputers in businesses has, by contrast, boomed. Vantage Research, a market research firm specializing in microelectronics, estimates that some 575,000 personal computers were sold in 1980, with Radio Shack, Apple, and Commodore the market leaders. The bulk of these, and especially the more powerful and more expensive models, are going to businesses. This means that the main market push for innovation is at the top end of microcomputer capability, not at the bottom end of simple price reduction.

Routine computations are increasingly taken out of the realm of computers proper, and given to specialized microprocessors preprogrammed to perform repeated similar computations. Some examples are microprocessor-based cash registers, and pocket calculators performing a very large percentage of routine calculations without requiring even minimal programmability.

DATA MANAGEMENT

Microcomputers are replacing clerical workers, not earlier computers or other electronic data processing equipment. This fact is crucial to understanding both their usefulness to managers and the resistances they encounter. Where microcomputer manufacturers are in competition with IBM and similar companies, it is for new implementations within an expanding market, much more often than for old users in need of new machines.[12] The new computer implementations come in three categories.

First, smaller and smaller firms and even individual professional practices are finding it cost-effective to resort to computer billing, inventory control, word processing, and the like. Second, branch offices of larger firms are finding that, whether or not they are linked via telephone lin (or other means) to a central office computer, it is useful to have immediate and inexpensive access to some of their own records; as for example, salesmen need data on only their particular territories, and to do word processing. Third, individual managers within larger firms are finding needs for their own computers. These may or may not be used as intelligent terminals for access to a central computer, and those of several executives may or may not be united in a network. Although engineers and technical managers are predictably prominent among such users, they do not dominate the field. Corporate planners, specialists in organizational behavior, and designers of various sorts join with line managers in creating this area of demand.

USES

The primary, though hardly exclusive, business use of microcomputers is to keep and later gain access to records of various sorts. Microcomputer systems costing between $4,000 and $8,000 are increasingly the basis for record-keeping among professionals such as doctors and lawyers. Relatively small memories are not a major problem in such uses, since client bases number in the hundreds rather than the thousands. Such computer file-keeping is extremely economical and reliable; it is frequently possible for a microcomputer to save an entire clerical salary and improve response time in searching for particular data.

Some other professional practices, such as architectural concerns, may use the microcomputer for more than simple file-keeping. Graphic potentials are considerable, and programs are potentially practical to check various complicated plans for routine sorts of errors, following the same principles discussed with regard to tax computation. Farmers are in the vanguard of professional use of microcomputers, keeping inventory and weather records and forecasting market trends (see Barton, 1979).

Business firms are likely to use computers as word processors as well as filing systems. Letters which are repeatedly sent may be stored for access and editing when required; billing is easily computerized. Filing functions are still significant here, however, as in inventory control. This is, to continue an example already used, the major benefit of computerized cash registers in grocery stores. Establishing stock on hand no longer requires a separate human step (together with its possible lost time if the store must be closed, or overtime wages if the work is done after normal hours). Precise inventory accounts are available instantly to managers or purchasing agents. Noncommercial organizations, such as libraries, are able to make excellent use of the same features. Already, major university libraries and the U.S. Library of Congress are in the process of converting to computerized cataloging.

While microcomputer memory is, as yet, not up to filing tasks of several million entries, microcomputers can access larger data banks either through larger computers or through the currently improving intermediate technology for reading discs. A microcomputer can act as an intelligent terminal, capable not only of giving access to a larger computer's memory, but of asking the larger computer specific preprogrammed questions, and transferring the answers to its own memory files. For example, a personal microcomputer could be connected, by telephone line, to the Library of Congress computer.

Its user, interested in improving a bibliography, might give his microcomputer a list of the relevant titles he already knows, and ask it to scan all the subject headings in which those titles appear, noting in its memory all the other titles listed with them. Later, users can scan such a list and ask the microcomputer to have any which they want printed alphabetically. Much the same service is available at present from reference sections of many libraries, but at a considerable cost, and with a delay of up to several days. All that microcomputers require to do this part of the job, cheaper and better, is software formulated to allow it to communicate directly with the Library of Congress computer.

Last, but not least, the highly touted but little realized educational potential of computers may get a boost from microcomputers. Computer-based instruction (like much, but not all, human-based instruction) is essentially a matter of data management. The computer needs to be able to provide its student with some specific sorts of information in an orderly fashion. Indeed, the major issue in creating such educational computers is in deciding what that order needs to be; it is easy to give the computer the necessary data.

There are several reasons microcomputers may offer an advance over their larger cousins in this area. First, they are small enough and cheap enough that individual students can use them when and where they want to. This is an equally major asset for children whose short attention spans but unpredictably recurrent bursts of interest could benefit from the availability of a computer teacher in the home, and for busy business executives who wish to brush up on their French, say, without leaving the office. Secondly, microcomputers offer much more rapid response time than did the generations of computers on which some people hoped to teach the children of the 1960s.[13] Students may interact with them at a fairly natural speed—much too expensive on mainframes.

Thirdly, microcomputers offer their student users the possibility of pursuing a variety of different courses of learning, even on prepackaged software—let alone if students learn to program for themselves. The wide range of software which the modern microcomputer can use makes it possible for the machine to engage the student in quite extended dialogue, not merely confirming or disconfirming answers, but actually explaining some of the underlying issues. Far from "depersonalizing" education, the use of microcomputers could, under the right circumstances, free teachers from routine tasks of supplying information and allow them much greater opportunity to teach their students to think and to encourage them in the development and expression of their own distinctive ideas.

Automation is generally applicable to any recurrent activity. Its advantages are speed, continuity, and reliability as well as reduction in labor costs. Growth in percentage of activities automated has been more or less continuous since the industrial revolution, with acceleration following certain major technological advances such as the steam engine, the construction of its electronic successors, and so forth. Essentially, the trend is for more and more different kinds of activities, especially more complicated activities, to be automated with less and less need for human intervention. The major limiting factors have been insufficient precision and flexibility in the motions of automata, and an incapacity for the machines to respond to changes in their environments. Recent microelectronic and related technology has overcome many of the limits imposed by these factors. For several years microprocessors have been able to instantly process quite complex equations to control detailed motions. Their low cost and tiny size make implementation attractive and convenient. Moreover, their speed opens the potential for much more sensitive machine response.

Programmable jigs and other machine tools have been available for at least ten years; microprocessors have simply improved them a little and made them a lot simpler and more economical. Such machine tools are not limited to single, finite tasks as earlier automata have been, but can easily be reprogrammed according to changes in product specifications. They are already important in electronics, automobile, and computer production, to name only a few areas. For three reasons they are likely to be much more important in the near future.

First, the major industrial countries—especially America, but also such recently thriving competitors as Sweden—are confronting a crisis of outdated plants. With probable government assistance, corporations will be undertaking a massive investment in new plants, therefore the markets for new, high-productivity technology will be large. Secondly, the cost and efficiency of such machines are being rapidly improved. The incentives for adopting the new technology are thus great, and the barriers low. Some automatons in the paper industry pay for themselves within 18 months—not a bad figure. The current American political situation is also relatively favorable for managers to decide to confront unions with demands for acceptance of new technology (see Noble, 1978, on the politics of technology with special attention to machine tools).

Third, the major remaining technological difficulty has in the last two years been very nearly overcome. Sensors were holding back potential automation, because of the difficulties already noted in digital/analog converters, and because of the complexity of the information with which the machines need to deal. The parallel array processor is already making great strides into the latter area; automata with "eye-hand" coordination are available, and their sensitivity is continually improving.

We tend to think of automata primarily in production processes (which is why we think of them putting people out of work). Many microprocessors will work—automatically—in other fields entirely. Examples are the microprocessors which automobiles now need. These control the combinations of air and fuel in combustion for catalytic converters to work well, and adjust the engine's idling speed and choke in order to achieve higher fuel economy. Numerous less central functions have been—at least experimentally—automated through the use of microprocessors: air conditioning sensitive to the weather, windshield wipers which detect rain, programmable horns, digital locks, computations of driving range on remaining fuel, and so on. Interestingly, Detroit's contracts in this area are going to Japanese firms which offer apparently better quality and higher reliability. The American producers are annoyed at the loss of prestige, but they still have plenty of customers in computers, consumer products, telecommunications, and, yes, industrial equipment.

A full treatment of automation would call for more consideration of fixed use hardware. Since this article is focused on microcomputers, I shall not go into this. A few more comments on the issues raised by automation are to be found in the section on "Problems" below.

COMMUNICATIONS

The issues already discussed may seem complex enough, and the possibilities already suggested for microcomputers may seem considerable, but the full effects of the technology depend on its marriage to advanced communications technology. In the first place, despite their increasing competence in isolation, microcomputers gain effectiveness when used in communication with larger computers and with each other. Possibilities for distributed intelligence and processing, which have never gotten much beyond ambitions with conventional computer technology, may finally become reality (Evans, 1980: 364; Lecht, 1977: 75-83). In the past, organizations have generally had central data processing offices, with limited access and a specialized set of experts. The new technology offers the possibility of removing the intermediaries almost completely from most systems, and decentralizing access even to large computers. If we choose to develop this technology—and parts of it are already being developed for other purposes—it will be possible to connect any microcomputer into almost any mainframe when necessary. As noted before, it will even be possible to have the microcomputer do much of the complicated programming necessary for communicating with the large computer.

The possibilities which this opens up are considerable. Let me suggest, briefly in both cases, what telecommunications can do for the computer, and then what the computer can do for telecommunications. In both directions of relationship, microcomputers are particularly involved. Several of the advances in microprocessor technology have been necessary to the improvement of telecommunications technology; switching apparatuses for telephone lines are a good example. In addition, it is the proliferation of microcomputers which makes the various possibilities we shall examine likely, though many of them would be technically possible with larger scale technology.

Microcomputers, as we have seen, are still quite limited in memory capacity. Modes of improving memory are expensive. Telecommunications is likely to make it cheaper for most purposes to have access to larger computers than to acquire and store large independent data files. Remote access by telephone to mainframe computers is becoming easier all the time. The two major limiting factors are communications bandwidth and the cost of telephone lines. Both are likely to be largely eliminated in the next few years. The spread of cable television already provides many homes with a much wider band, so that graphics and other complex data representations can be communicated.

Optical fiber technology is important. Optical fibers, extremely thin strands of glass, can transmit more information more rapidly than conventional copper telephone wires. They can also be packed many more to the same width of cable. While copper is scarce and its price rising, glass is made from supremely cheap silica—sand. For longer distance communication, satellite transmission is becoming increasingly important and economical. Though there are political problems and concerns over the clutter of objects orbiting the earth, huge sums are being spent to develop this technology. Effective satellite communications would devalue existing long distance trunk lines owned by the world's telephone companies, however, so a political and economic problem of paying for more efficient public goods arises. There are no major purely technological hitches to achieving the telecommunications capacity to link all the world's computers—large and small—to each other if desired. The cost will not even be prohibitive, amortized over the next couple of decades (though I do think the process will take longer).

Microcomputers, in fact, may have been the missing ingredient in the recipe for major telecommunications advances. While better access to large computers increases the market for microcomputers, it does so only within the field of people who are likely computer users anyway. Much more potential comes from the possibility that the telecommunications/microcomputers marriage will transform the basis of a wide variety of activities not previously the primary province of computers, and thus affect the majority of the population.

It is in this new combined technology that the possibility of really transforming social life appears. The common predictions for computers controlling all sorts of home appliances are indeed possible (Motorola has built a sample computer house in Arizona), but far from revolutionary. I would rather have precise computer control of my thermostat, but, though it may save me a few dollars on my heating bill, it won't change my life. Indeed, of all the home appliance possibilities the computer opens up, the one I find most attractive is the possibility of using the telephone from my office—say, to direct the heater to warm up the house for my return or to make sure I did remember to turn off the coffee pot. Most of the potential in the home is either trivial, or for the sort of purely created needs—things we didn't know we wanted until we saw them advertised. The new possibilities in communications transcend this level of social and personal epiphenomena.

At present, an increasing proportion, probably long a majority, of the communication in our society is one-way. We receive television and radio transmissions, newspapers, magazines and other mail, and we have very little opportunity to respond. For most of us, active communication (rather than mere passive receipt of messages) is limited to direct and specific interpersonal relationships with friends and immediate co-workers.[14] We may speak face-to-face, talk over the telephone, or, more rarely, write letters. Having microcomputers hooked up to a sophisticated telecommunications system could change that.

Consider, to begin with, the possibilities for electronic mail. Thousands of trees are felled every week in order to deluge us with masses of paper, a tiny fraction of which we may want, though even that is difficult to store. It is within the capacity of technology now beginning to be implemented to replace all that by computerized electronic transmissions. Any individual or organization wishing to send a message to another would simply instruct its computer to do so; the message would be sent to the receiver's computer where it would be stored until wanted. Some "mail" could be automatically rejected, if desired; items of special importance could be not only read but printed. The use of the new technology would speed up mail delivery by several days, and quite possibly reduce costs. It would be possible to have different priorities for transmission; since few items would be urgent and only direct conversations need to tie up a whole line, transmissions could simply fill in the spaces between such high priority uses. Whole newspapers could be transmitted, and/or made available, and users could choose those parts they wanted to read. The need to limit the size of the paper would be reduced. The biggest catch here is the relatively unattractive display offered by cathode-ray screens.

This sort of electronic data transmission is clearly just an extension of the systems which businesses already use to communicate with branch offices. It is likely that in the future there will be improvement in the latter as well, with what may be called "teleconferencing." Although this is unlikely to ever wholly replace face-to-face communication, it can cut down on business travel and improve corporate "reaction times." The capacity of computers to transmit graphics is a major asset here, since it will allow virtual electronic flip-charts; two executives a thousand miles apart will be able to go over data which appear instantly in front of both of them. In some cases, video transmissions may be important. I personally suspect that this will be less so than science fiction has led us to anticipate, partly because video will remain expensive, but also because we will remain stilted in front of cameras.[15]

The sort of data which are likely to be transmitted in this way would go well beyond what we currently receive in the mail. The British Broadcasting Corporation's Viewdata system gives a hint of the possibilities. It has been slow in operationalization (largely due to the expense of equipment), but basically, a subscriber, for a fee, can summon up a wide variety of information from a central computer data bank for display on his or her television screen. The limit to the system is, primarily, its passivity. One has only the option of reviewing the data selected; it cannot be preedited in any special way, nor can one conduct a dialogue with the computer. There is, however, fairly considerable consumer demand, which one can only assume would increase with greater capacity and flexibility of the system. It is a short step from Viewdata to the possibility of two-way communication.

Until now, the fears of those studying mass communications technology have been of an ever-increasing passitivity of information consumers (e.g., Hansen, 1980: 13, 17); the microcomputer may reverse at least one social tendency of the same technology of which it is a development. France is the world leader in marrying telecommunications with the computer; there (and hereafter in this article) the field is called telematics.[16] Advances in this direction would have a number of implications and possible uses. The media might become much more specialized, so that the specific readers if they wanted could choose articles directly from computer syndication services, instead of relying on the editors' selections. The same could go for television, which would not have to sink always to a lowest common denominator. On the other hand, editorial skills would still be in demand to help people make their choices from the wide range of data. This will remain particulary important as long as computers continue to have very low capacities for scanning and selecting among materials themselves. Better programs need to be written for the machines to avoid having to read every datum in order to find the desired few.

Telematics could speak to some of the problems of deterioriation of professional skills by offering the possibility for updating programs of advanced education. Education, in general, has enormous potential for redesign to use the new media. As has already been suggested, that part of the teacher's role which is simply transferring information can readily be taken over by the machine.[17] Routine drill and practice exercises are similar "naturals" for computers. But at that point the independent competence at the computer stops. Televised instructional programs like Britain's Open University start from the other end. They transmit films, some but not necessarily all of which may be of teachers, to widely scattered students. The problem here is that the students are passive listeners (which is just as much a problem, of course, in large university lectures, unless the professor is a particularly good orator or actor). Having the broadcasts reach students equipped with microcomputers as well as televisions would allow interaction. Colleges and universities may have little of their formally declared stock in trade to offer prospective students unless they can learn to maximize personal contact among students and faculty—the intellectual community. (Of course, they will always have collective beer drinking and dating to attract a clientele.)

The use of telematics for education has some particular advantages for developing countries in which teachers may be scarce and target populations remote. I think these have been overtouted in the literature, however, at least for programs going beyond the mere transmission of basic literacy lessons to passive listeners. In fact, I think that the computer/telecommunications developments are likely to exacerbate the crisis of literacy which the world faces today. This problem creates gaps between portions of the populations of developed countries, as well as between the most and least developed countries. Making use of the computer requires a fairly high degree of literacy (and, even in "natural language" programs, a fairly standard linguistic usage). If we do introduce much use of computer communications into society, we shall need urgently to eliminate illiteracy, or we shall disenfranchise part of our society from even the rudimentary social participation it has at present.

Participation in public affairs is, indeed, an area in which computer communications might become very important. In Higashi-Ikoma, Japan, the world's first city to be entirely wired with optical fibers, citizens regularly take part in televised conversation shows without leaving their homes. Already some special programs in the United States have created such interactive television systems for the elderly and some other special populations. It certainly could be used for town meetings, and combined with computer terminals to allow the registration of opinions on key issues. Some observers see great promise in this development for a return to plebisciterian democracy but on a scale far from that of city-states, Rousseau's Geneva or New England town meetings. That possibility bothers me; like Tocqueville I worry that citizens would be entirely ineffective as individuals and would need some intermediate associations to inform them and protect them from the tyranny of the newly possible instant majority, or of the central government (Calhoun, 1980). It certainly seems a good idea to open some public meetings to wider citizen participation; perhaps we may want to consider whether the technological possibility of a radically plebisciterian democracy is one we want to invest in.

Perhaps here too the computer/communications linkage offers a possible solution to this problem (only partially) of its own making. It has been observed by some social commentators that just as secondary relationships (face-to-face but of limited content) displaced primary relationships (close and of diffuse content, like family) in many areas of our lives, so tertiary relationships (among people who never meet directly) are coming to predominate. This may be true if one looks at simple numbers of relationships, but not if one considers their importance to the individuals in question. In any case, it may be that computer communications offers primary relationships some possibilities for new strength and growth. An extension of telematics into telecommuting is already beginning. Working for large organizations without leaving home may offer some considerable advantages for family solidarity and community-building.

Commuting distances are themselves a problem for many American communities. High fuel prices only exacerbate the problem. So far, most investment in combating our dependence on imported oil has gone into trying to find domestic reserves or substitutes. Some efforts at conservation have been made, but they have generally been cast as morally obligatory sacrifices. Less consideration seems to have gone into the possibility of improving the fuel situation by lessening demand through creating viable alternatives to commuting. It is just that which telecomuting may do. Telematic links between a home and both other homes and places of businesses would allow for a variety of work to be done without moving people. Information would be moved instead, and much more cheaply. Two costs would need to concern managers. First, to whatever extent their control over the workers in question was based on proximity and immediate supervision, it might be lost. Secondly, to whatever extent organizational functioning depended on informal lines of communication linking employees—say, around the watercooler—substitutes would have to be found. I have spoken elsewhere to the latter problem; let us consider the former.

The most significant kind of work which could be transferred from central office to place of residence (or wherever the individual wished to plug in his computer) would be intellectual work. Manual production of all kinds would be more difficult to reorient. I have already noted the likely reduction in demand for low-skilled, primarily mental, work—such as typing and filing. The upshot is that the people most likely to be doing their work away from central headquarters are those already most difficult to control directly; they are workers motivated and/or disciplined from within, not constantly supervised or coerced. Effective ways of measuring productivity would have to be developed, so that payment could follow results rather than merely time spent at work. This is already pretty much of the case at the higher end of white collar work, and even at some parts of the lower end, such as sales. Managers have not generally been willing to extend the same autonomy to workers lower in the hierarchy; they may now need to, and correspondingly may need to think about and experiment with new forms of organizational structure designed to take best advantage of interaction among relative peers and the involvement of individuals and subgroups in organizational activity (Calhoun, 1980).[18]

Workers—white or blue collar—have not always been attracted by proposals to pay them by results. A seemingly fairer and more efficient remunerative system has several times been derailed, and the fault must be shared by managers and workers alike. The latter have often taken the introduction of payments by results—like piece rates in sweatshops—to be only a way of increasing the rate of exploitation of labor.[19] This is largely because they have been precisely so used by managers. Acceptance of payments by results will depend on some combination of (1) the work itself being made interesting for more people, (2) trust being established that the goal of the exercise is not to intensify exploitation, and, I suppose, (3) workers having no alternative.

However justified many workers' fears of "sweating" through payment by results, i.e., of driving down the wage rate, they are not universally applicable. One need only notice that managers are paid at least in part by results, to realize that it is not the technique, but the structural context of the use of technique which determines whether wages will be driven down. Workers' wages will be driven down because they are in a position of low power; powerful groups mobilized to defend workers might demand just the opposite—some form of maintenance of "fair" remuneration through an agreed upon system of payment by rewards (some workers demanded this during the industrial revolution). And, it must be noted, many workers prefer bureaucratic systems (in the partially pejorative but still Weberian sense of the term) precisely because they can exert low effort in return for secure salaries. The workers may be white or blue collar, but the organizations in which they participate infuriate us all. They may be a casualty of telematics (I hope rather more than assert).

Working from the home would offer the people involved (workers and their families and friends) many advantages. It would allow one to choose a good deal of one's lifestyle independent of one's job; it would allow people to spend more time with their families and less in such tedius tasks as commuting; it would increase the flexibility of time use; it would allow children to understand what their parents did for a living and at the same time make childcare and education both easier and more of a family matter; and it would allow partners in two-career marriages to pursue their careers much more fully without jeopardizing their spouse's career. That there might be considerable demand for this sort of arrangement is evidenced by the increasing difficulty large corporations are having getting their excutives to move around the country while climbing the corporate ladder. Of course, for such a manner of living to develop would take considerable time and investment, while patterns of work, residence, and consumption gradually changed. Both the social infrastructure and the personal habits of the people involved would inhibit rapid transformation.

PROBLEMS AND RESISTANCES

Microcomputers and allied technical developments offer many advantages to society at large and to particular interests within society. They also offer a variety of perils, so innovation proceeds slowly and not necessarily in the most fruitful directions.

TECHNOLOGICAL OBSOLESCENCE

This is not just a problem of resistance; it is also a problem of uncreativity. For example, if computers are to be widely used in education, a new understanding of the job of teachers must be reached. If some computers put workers out of jobs, then new jobs must be created. If once restricted data becomes widely available, then organizational systems based on control of scarce information will become obsolete and need to be revised. Change is not slowed simply because people like the status quo ante, or even because they fear uncertainty. Often, it is blocked because people fail to create good *new* ways of acting, thinking and relating to each other.

At the highest levels, we have so far utterly failed in modern capitalist (and I think pretty much existing socialist) societies to find a way of humanely and productively dealing with technological obsolescence. Obsolescence is something that, taking society as a whole, we both fear deeply and seek constantly to create. There can be few innovations which do not produce corresponding obsolescence. Our society depends on continued innovativeness; we must, therefore, come to grips with obsolescence, see that it is more than mere accident or linear phenomenon of depreciation, and develop a coordinated plan for dealing with it. Though individual experiences of obsolescence in certain firms or whole technological areas may be only temporary, a significant proportion of the total economy is, at any given time, suffering under the weight of obsolescent technology. Individual managers and concerned citizens alike blind themselves to it only at their peril.

The record of society's failure to rapidly find good new solutions to problems which are the unfortunate byproducts of technological innovations is one of the major sources of the widespread resistance now manifested toward the microcomputer, indeed, toward the computer generally. Trade union leaders, for example, are often concerned about the new technology not because of a general fear of change, but because of the belief that our refusal to deal effectively with the problems of obsolescence will *not* change. They are not just uncertain about the effects of computers on the workplace; they are certain that workers put out of jobs will face long, hard struggles to regain their previous standard of living—even if society grows richer overall. If the computer industry wishes to find continued large markets for its products in a reasonably stable society, it would do well to put some of its creativity to work finding solutions to the social problems its technology threatens to create. The words of dissident computer scientist Joseph Weizenbaum are salutary:

> No fix, technological or otherwise, of the American education system that does not recognize that American schools are rapidly becoming America's principal juvenile minimum security prisons can be expected to have socially therapeutic effects. Giving children computers to play with, while not necessarily bad in itself, cannot touch this or any other real problem [1979: 440].[20]

Though this sort of concern may be the source of much resistance to computers, it is worth bearing in mind that resistance is, I think, unlikely to be the solution. Addressing energy to the social problems themselves, whether caused by or independent of the new technology, is more likely to help.

DEHUMANIZATION

Resistance to the new sorts of computerization made possible or practical by the microcomputers comes from several social sources for varying reasons. With regard to home computer use, cost is still a major factor limiting acceptance. Systems for homes cost from $600-$3,000+, with only the upper end able to do many things which have been suggested microcomputers can do. Home computers remain, therefore, primarily the province of hobbyists, the rich, and those who, like mathematicians or sociologists, can use the machines in their work. Outside of the United States, especially, home computer markets have been tiny. Considerable lowering of costs and/or future technological advances—especially, I think, in telematics (see the next section)—must take place before this market will become really large. That is, nonetheless, a fairly near-term prospect.

Much the same concern over cost, together with software shortages and resentment over "dehumanization" is at issue in education. In the business area, cost is a less fundamental factor in resistance (though it may influence choice among competitors' products). Questions about microcomputer capability are more significant, and combine with less rational issues of the prestige attaching to size and power of computing equipment. Pride may cause executives to purchase much more hardware than they need. On the other hand, resistance may come from all sorts of workers and managers.

There is a widespread hostility to the display screen, and to the "impersonality" of the computer. Resistance to the display screen begins with the optical problems discussed above; screens really are unpleasant and sometimes dangerous to look at for extended periods of time. It goes beyond this, though, to a positive preference for paper over electronic media. Reasons are largely obscure, but include a sense of impermanence, the lack of any tactile gratification, and, especially in the case of writers, the difficulty of looking back a page or two at what one has just done while one contemplates the next sentence.

It is likely that a good deal of this sort of resistance will fade with familiarity. While attractions to the paper media will remain, benefits of the computer, as they are recognized, will come to counterbalance them. In fact, the process of getting used to computers will begin, for most people and especially for future generations, well before individuals arrive at workplace uses. The proliferation of computer toys and games is already making Americans, and increasingly Europeans too, familiar with display screens. Any implementation of computer-assisted education would extend that familiarity to the keyboard and to the functions of the computer itself. Computer manufacturers who would like to sell their products to businessmen, and businessmen who would would like to buy them but are unsure whether their employees will accept them would both do well to encourage educational and other uses which will familiarize the public with microcomputers.

The impersonality of the computer is another problem, though perhaps much less of one than has been imagined. It is a problem because human beings will make more adjustments to the specific identities of those with whom they are dealing with than a computer is likely to. This is part of the frustration we commonly feel when, after years of paying our bills on time, the phone company or some other firm or utility threatens to cut off our service because of 50¢ overdue on our account. Similarly, within offices, communication through computers loses many of the nuances which give important meanings to statements; in this way it may exaggerate a sense of lacking commonly felt about telephone conversations as opposed to direct interaction. But, this impersonality can in some cases be an asset.

Studies have found that patients respond quite favorably to being interviewed by computers, say, upon admission to a hospital (Price, 1980: 67).[21] In many cases, patients even preferred the impersonal computer, which spared them both embarrassment and the extra expenditure of energy which human interaction can demand, but which they were not in the best of positions to give.

Unlike doctors, computers are generally neither impatient nor condescending. Unlike all sorts of interviewers, computers do not seem to carry the threat of moral disapprobation (perhaps because people do not quite so readily project their own fears and guilts onto computers, though it must be admitted that projection does take place). This has proven capable of generating widely varying results. Alcoholics, for example, are likely to report as much as 50% more alcohol consumption to computers than to even the most sympathetic of human interviewers (Evans, 1980: 113). In offices, it has generally been found that increased reliance on computer communication does not so much reduce the quantity of information which flows directly among humans as change its contents (Eason, 1980: 140; Mintzberg, 1973).

The issue here is not just presence or absence of human contact. It is probably true that, in many cases, "human contact which is lost by the use of the impersonal data technology must be reestablished in some other way" (Hansen, 1980: 13). But we need to recognize that not all human contact is pleasurable. Computers and telecommunications do not just eliminate human contact, they increase human choice as to the source and content of such contact. Thus, executives who give up face-to-face meetings at corporate headquarters in favor of telecommunications may be increasing the amount of interaction they can have with their immediate co-workers and/or their families. Moreover, if computers transfer information, then human beings can deal in less routine matters when they communicate directly—this is part of the potential advantage, as noted, to computer-assisted instruction; it might apply equally well to different design teams working on a common product. Overcoming the resistance based on fear of dehumanization will depend on convincing the public that these advantages will accrue; that is, of course, not just a matter of education, but also of ensuring that computers will be used in that way.

Part of the fear of impersonality is really a fear of what people one is not in immediate contact with may do with records of one's activities. Thus, the introduction of central data processing equipment in corporations in some cases has failed to produce the desired productivity gains. Workers have gone out of their ways to keep from leaving the sort of records which managers might later check.

This has been particularly a problem in the white-collar areas where workers—who might be not only secretaries but well-paid executives—are used to high autonomy. Thus, the phrase "the computer is impersonal" may mean, "I don't know who is looking at computer records." The whole knotty question of privacy is thus an intraorganizational as well as a societal problem.

Safeguarding personal privacy is already difficult and promises to get much more difficult as information technology advances. In the first place, the legal status of any "right" to privacy is uncertain (see Michael, 1964). At the very least, it is in conflict with the public's (and presumably the press's, probably the governments') right to know. At present, only the most minimal of efforts are made to protect individuals from the use of data, which they have willingly given, in ways of which they may not know. Even with regard to data gathered without individuals' permissions, such as the products of government investigations, these exists not so much protection as simply right of access. Some real progress in confronting this problem will have to be made before resistance on this basis to new computer technology will be eliminated.[22]

The problem of privacy is closely related to that of crime. which it is just as well to mention here. The massive use of electronic media for funds transfer, together with the increasingly likely storage of private information in computers, provide opportunities for a new kind of highly skilled thief. Already some spectacular thefts have been perpetrated—presumably more than we know of. Osborne (1979: 134-142) has pointed out some of the dangers in electronic funds transfer systems and suggested that they are not worth the potential costs and should be outlawed. I believe his argument has to do particularly with bank to bank transfers, and it is salutary. Several popular accounts (e.g., Martin, 1978: 101-102)[23] have dismissed this issue by arguing that computer codes will be so hard to break that we are quite secure. This misses the point, that most sophisticated computer crimes are the deeds of insiders of one sort or another.

The extremely large computer programs discussed earlier make thefts difficult to trace and put skilled programmers in a position of considerable opportunity and little accountability. Such crimes are not committed on microcomputers. But microcomputers are potentially quite involved in electronic funds transfers, so it is worth noting that the field does not end with bank to bank transfers, and that Osborne's suggestion might need to be taken only narrowly. In addition, there are transfers between individuals and banks through machine tellers and the use of credit cards, and between employers and banks with automatic deposit of payroll funds. Even though these are not mainly microcomputer issues, problems are likely to hurt the public image of computers in general.

ORGANIZATIONAL INERTIA

The second major source of resistance to the new possibilities microprocessor technology opens up is organizational inertia and the commitment of individuals and groups to specific routines. Perhaps the most clearcut example of this kind of resistance is the response of business executives to the possibility of losing their claim to specific secretaries. These same executives often criticize unions for a "knee-jerk" negative response to new technology; they are, in the case of secretaries, at least as guilty of such negativism. Beside typing letters, answering the telephone, and keeping track of the files, secretaries have two other sorts of functions which account for the tenacity with which executives cling to the institution.

First, secretaries are in the status-giving business; they act to define executives. They do this in several ways: by merely existing, and thus showing the importance of their employers, by acting as buffers between their bosses and the outside world, and by being demonstratively subordinate. Secondly, secretaries perform part of the jobs for which their bosses receive the credit. Secretaries keep their bosses on time and headed off to the right appointments; they assemble the data executives need to execute their decisions and other organizational functions; they remember what client had what problem with what product and who to call in shipping if one's products aren't reaching one's clients on time. Secretaries even compile the data which go into reports to one's superiors. Would it be the executive or the executive's secretary who got replaced by the microcomputer? The most important declared function of many executives say, branch managers, which could not easily be transferred to machine or secretary is decision-making. The secretary might take over minor decisions (with a suitable change in title), and telecommunications would allow the rest to be transferred to a central office or a higher level of the organization.

The whole power hierarchy of organizations could be dramatically changed by the large-scale computerization which microprocessor technology is likely to make practical. For one thing, systems analysts will usually acquire power in any implementation (Pettigrew, 1980: 43; see also Hedberg, 1980: 25-27, on obstacles to system-designer sensitivity to user needs).[24] For another, control over information is less likely to be a major source of power, as is currently the case in many organizations (see Handy, 1976: 116-119; Drucker, 1973). Computer systems themselves are usually implements to support specific organizational functions (Eason, 1980: 135), and are, therefore, likely to specialize information in the hands of those who control those functions. This will not necessarily change the significance of those areas in the organization as a whole, but it will affect the control of managers within these units.[25]

Microcomputers can facilitate greater centralization or greater decentralization (Simon, 1979; also Hansen, 1980: 12). A number of analysts have argued that recent development in computer technology increase the need for self-designing organizations (Hedberg, 1980; Mumford, 1980: 104; Docherty, 1980: 114-117). I suggest, however, that the technology is flexible, and can be used either for control or to encourage greater democratization of and participation in management (see Tricker, 1980, on the general issue of freedom vs. control in computer utilization).

Another major issue for the future of microelectronics is the fragmentation of markets, in which different types of equipment (and sometimes similar equipment from different manufactures) cannot readily work as part of a common system.[26] Some firms have delayed investment in microelectronic technology hoping that standardization will take place (and perhaps expecting prices to come down still further). Indeed, the highly competitive nature of the microprocessor-based market worries some potential buyers. They are afraid that if they invest in a single company's line of products, they will be committed to that in the future, even if another company wins technological races, or, worse, the first company goes broke. Some firms find themselves with no way of uniting their word-processors, microcomputers, and the like in a network. Network creation is particularly important to making effective use of microcomputers.

Xerox has developed, and is just beginning to market, together with Intel and Digital Equipment, a system called Ethernet specifically for the purpose of connecting dissimilar machines. It can, at present, unite up to 128 of them over short distances through coaxial cables.

Software is another problem. With the advent of microprocessor technology, software has become the major expense in computing. The bottleneck caused by a shortage of programs for the new equipment may be eased somewhat, but the cost problem will probably be helped only slightly. Software can be prepackaged, but even where sold in large numbers it does not gain the same economy of scale as hardware. Moreover, many software demands require high individualization, and therefore will keep software production a labor-intensive branch of the industry.

Of course, this labor is in part being contributed very cheaply by small entrepreneurs and hobbyists who willingly spend long hours developing esoteric programs for relatively slight and highly uncertain financial rewards. The benefits of such labors will not always be available, however, especially to those need to develop a specific program on demand. More promising is progress in computer-assisted programming. This is making it ever-easier to communicate with microcomputers, and through them to larger computers. In the future, machines will communicate in a simple and/or fairly natural language with the user, discern his or her aims, and write the object program themselves.

In overcoming these market problems, microcomputer technology has several advantages over mainframe computers. Three significant ones are: (1) Investments in large computers tie organizations to specific operating systems and particular kinds of computer technology. IBM's long-term lease contracts and exclusive software are case in point (though they are now challenged by imitators like Amdahl). It is much easier to keep updating a system based on more or less autonomous microcomputers than to change from one mainframe base to another. (2) There have been frequent delays in the introduction of new mainframe models—notably IBM's latest. These combine with the size and long-term nature of the investment to give ulcers to those who must choose data processing equipment. (3) Microcomputers do not, at least to equal extent, mean the introduction of new experts, with new power, into organizations. For the most part, they can be used by the individuals most directly involved with the information in question, and thus can, if desired, follow at least a significant part of the existing organizational structure.

WORKERS'FEARS

The workforce which will be most affected by microcomputers will be office staffs. Automation is, of course, increasing and having increasing effects on blue-collar workers. But, the blue-collar workforce is in any case a shrinking proportion of the whole, and considerable parts of it are likely to remain immune to automation for a considerable time to come. It is clerical workers, low-level managers and other moderately skilled white-collar worker with whom the microcomputer most directly competes.

White-collar workers now compose over half of the United States' active workforce, and the proportion seems to be growing.[27] Leading the way are service industries, which are labor intensive, often low-productivity, and prime candidates for computerization. Their employees are also heavily disproportionately female and somewhat disproportionately minority. Putting them out of work would hurt those least able to afford troubles, and would be especially politically sensitive.

Though file clerks, typists, and the like are definitely endangered by the computer, a premium is paid for those who have certain new skills. Secretaries skilled in the use of new word processors can command as much as $35 an hour in Manhattan. On the other hand, some white-collar skills which now seem to be booming will soon be crashing. At the moment, computer programmers are in extremely short supply. Advances in computer-assisted and automatic programming, however, may combine with the increasing ease of operating microcomputers to put much of the profession out of business. The new machines increase the demand only for very highly skilled programmers, not for the run of the mill.

White-collar workers should feel some of the concern about unemployment already voiced by their blue-collar brethren. One has only to pause and consider how many white-collar jobs—including some very highly paid ones—depend largely on giving information over the phone or in person. If an investor could, through his own computer, get market data—including up to the minute stock quotes—and issue his buy or sell instructions, would he be likely to pay a stockbroker? Of course, stockbrokers might resort to the same attempts they decry on the part of unions, and demand that the technology to kept from threatening their jobs, perhaps by denying fully computerized firms access to the exchanges. I doubt if they could succeed, though, and many brokerage firms will probably be happy to dispense with most sales personnel and simply market their research reports through computers.

Members of other highly trained professions might suffer some of the same threats as the stockbrokers. After all, to a considerable degree, lawyers, doctors, and other professionals derive their status from controlling access to specialized information. Computers might aid them in their work, for example, in searches for legal precedents or medical diagnoses—but then the computers and not the professionals become the repositories of much of the information. If their productivity is increased enough, or if the public can take over enough of their tasks for itself, such professions might lose their positions of power. They too can be expected to resist. And we might be on the lookout in the meantime for another sort of social problem, exemplified by the doctor who lets his medical knowledge become too far out of date and relies too exclusively on the computer for his work (see Osborne, 1979: 71-102 on the white-collar future).

A good deal of flexibility characterizes the potential effects of microcomputers on the labor force. Union and worker concern over job security and pay is going to come into conflict with concern over occupational safety, health, and working conditions. There is however, no basic reason why, given appropriate planning, microelectronics cannot improve and rehumanize work. The decline of artisan skills and autonomy has often been noted and lamented. Automation using microprocessors holds the possibility of eliminating low-skilled jobs by transferring them to machines, rather than eliminating high-skilled jobs by transferring them to low-skilled workers (the process primarily described, for example, by Braverman, 1974).[28] Some workers and trade-unionists have noted that microelectronics may offer them benefits, particularly in the area of safety, but are concerned with what price in loss of control or other ills they will have to pay (Hansen, 1980: 15; Docherty, 1980: 123; Norman, 1980; European Trade Union Institute, 1979)

More than anything else, however, trade union resistance is based on fear of unemployment.[29] Only a handful of western industrial countries have shown a strong commitment to minimizing unemployment; the policy of most has been to allow fairly high rates and partially ameliorate their effects (the Scandinavian countries and Austria are the major exceptions). It is therefore not surprising that workers look askance at new labor-saving technology. Whether computers will reduce the work week as some of their advocates predict, or increase the unemployment rate, will depend largely on governments and/or concerted trade union activity. If unemployment rises, of course, social instability and high welfare expenditures may be a burden on all of society, not just the companies which helped to produce the crisis. In short, trade union resistance to microelectronic innovation can be expected to continue as long as we lack a full-employment policy. If the boldest claims for microelectronics are true, presumably we can afford one.

CONCLUSION

I have argued: (1) The technology on which microcomputers and allied developments are based is rapidly progressing, but that the extent and directions in which development continues will be largely determined by social, not autonomously technological, factors. (2) This technology can, within the next decade or two, advance to the point where all of the applications discussed will be practicable—not just technically but also in terms of cost. (3) A wide variety of applications are, or soon will be, underway for microcomputers and allied technologies in the areas of computation, automation, data management, and communication. (4) These will have enormous social implications. (5) The applications themselves and their effects are at least partially subject to social control. (6) It will be up to societies, at least in the advanced industrial world, to determine whether they benefit from or are hurt by the possibilities inherent in microelectronic technology. All sorts of individuals and social groups may gain or suffer. Social organization is the key variable determining which outcome will occur.

NOTES

1. For convenience, take "microprocessor" to refer to a single microelectronic circuit (which is printed on a chip in today's technology) containing a complete set of logic for autonomous processing. A "micro-computer" is a programmable device, equipped with memory capability, using a microprocessor for its central processing unit.

2. *The Economist* (May 12, 1979) reported TI raising its 1978 estimate of $24 billion by the late 1980s to a 1979 one of $32 billion by the same time. This gives an idea of the unpredictably rapid growth of demand in the field.

3. Osborne (1979) is a popular history of the microprocessing boom, especially good on anecdotal accounts of corporate fortunes. Another introduction, more thorough and calmer in tone, but less insightful and readable, is Barna and Porat (1976).

4. Figures such as this can be no more than educated guesses, since no accurate statistical records exist for the field as a whole. This estimate comes from Dataquest, a market research firm. Unless otherwise noted, market data in this paper comes from

The Economist; technical discussion is based on articles in various of the IEEE journals, the *Microprocessor Newsletter*, the *Sigsmall Newsletter*, *The Economist*, and personal conversations with technical experts. I have given citations primarily only where a datum is not common knowledge within the field, and concentrated on the social issues; my technical survey is, I believe, up-to-date and accurate, but hardly original.

5. Microprocessors, of course, may be used in controlling the memory functions of larger computers. Intel's 8800 will probably have this function for large data libraries being used by widely dispersed terminals—one of which may be microcomputers.

6. A recent special issue of *Science*, April 4, 1980, discusses several of these developments in optics.

7. In 1979 worldwide sales figures, the top five are Texas Instruments, National Semiconductor, Intel, General Instrument, and Zilog (The Economist, May 12, 1979: 115, and August 2, 1980: 63).

8. Between 1976 and 1980, the Japanese government and five major electronics concerns spent a pooled $400 million on research and development, especially focused on fabrication technology (The Economist, April 5, 1980: 74). The success of the strategy further illustrates the insufficiency of the entrepreneurial explanation.

9. Inmos has produced an interesting study forecasting the implications of microelectronics (Barron and Curnow, 1979).

10. This is one of the major sources for concern over the implications of new uses of computers. See Kling (1980) for a general review of the literature. Parker (1976) is the major work on computer crime. On the specific implications of electronic funds transfers, see King and Kraemer (1978). Osborne (1979: Ch. 7) offers a readable account.

11. The fact that many of the uses of home computers do not correspond to needs consumers had previously recognized has much to do with this. The cost is more of a barrier to artificially created needs.

12. The reasons for old users not going very often to new hardware bases are several, including especially long-term lease agreements for large computers, commitments to software, and operating systems designed to meet the demands of existing computers. The main reason for competition being focused on new markets, however, is simply that the cheapness of new computers—large and small—is opening new markets.

13. I can personally remember a 1960-1961 vintage computer which asked questions of the members of my third grade class at the University of Chicago Laboratory School. Its questions were rigidly prestructured and its confirmation of answers was slow, so no real dialogue was possible. On the other hand, the machine was apparently a behaviorist and gave marbles for correct answers.

14. Even face-to-face and other direct communication may, under some circumstances, be one-way, as when one's boss gives an order. The computer may, by redistributing access to information, reduce even this dimension of passivity. On some of the related issues of organizational structure and participation, see Calhoun (1980).

15. Cinematographic technology has not made great strides, with the result that camera lenses must be positioned near screens, not in them, making Picturephone and similar transmissions always appear awkward. If one looks at the image of the person one is conversing with, one appears to look away. If one looks into the camera, one loses sensitivity to the image of the other.

16. See Nora and Minc (1980) and *The Economist* (March 15, 1980: 83-84) on the French developments.

17. Of course, if students were literate, it could be done by books. See below on how the computer/telecommunications linkage may exacerbate a literacy crisis.

18. In fact, the computer would probably make it easier to judge individuals' or groups' contributions to productivity—and thus apportion awards. I have suggested (1980) that payment by results is likely to work better if groups, rather than individuals, are the loci of functioning and objects of evaluation.

19. Marx considered piece-rates "the form of wages most in harmony with the capitalist mode of production," because "the exploitation of the labourer by capital is here effected through the exploitation of the labourer by the labourer" (1867: 521-529). See also Braverman (1974) on Taylor's "scientific management" and the use of piece-wages to intensify exploitation. In Marxian terms, a technological need for capital to eliminate time-wages in favor of piece-rates might be taken to further indicate the workers' need for socialism.

20. Weizenbaum overstates his case, since giving children computers may address real, if not necessarily the most serious, problems. Bell's (1979) reply is largely accurate, though rather more hostile and defensive than the original article warrants. Bell attacks Weizenbaum's grounds of argument but does not really come to grips with his main points.

21. Similarly favorable responses were made to telecommunications with a doctor, where video and sensory data were included. See references and discussion in Martin (1978: Ch. 3).

22. The issue of computers and privacy has spawned a large literature of its own, and I have barely scratched the surface of a complex set of problems. See Westin (1967, 1971), Westin and Baker (1972), the important work of the HEW Advisory Commission on Automated Personal Data Systems (1973), the report of the Privacy Protection Study Commission (1977), Lauren (1973), and Rule, McAdam, Stearns and Uglow (1980). See also Briefs (1980: 56-57) on government-business interpenetration as a concern for trade unions. The popular discussion in Martin (1978: Chs. 20, 21) is perceptive on several points, though rather glib in its suggestion of the solution of having computers check on other computers.

23. Martin (1973) gives a more balanced treatment, leading me to think the later error was an oversight.

24. Note, though, that microcomputers might eliminate some of the need for elaborate, expert-designed systems which mainframes produce, and thus give end-users more control.

25. Thus Eason (1980: 143) and colleagues found that computer implementations produced greater change within departments than in relations between departments. They also produced greater change in the most certain managerial environments—which were presumably those where information could best be controlled.

26. Indeed, discussions of interfacing problems take up a very large proportion of the pages in technical books and journals devoted to microcomputer technology. Artwick (1980) is a recent general treatment.

27. If one includes service workers, some 52.5% of employed Americans are white-collar workers, the largest group of them being clerical workers (Bureau of the Census, 1979: 523).

28. Computers may have still another positive role to play in the lives of workers. This stems from the fact that many earlier innovations in production were designed largely to increase management control of the work-process (see Braverman, 1974). Attempts to "rehumanize" the workplace have recently seemed important to managers

seeking to increase loyalty and productivity of employees, and to workers themselves. Many such attempts have involved returning some autonomy to workers, either individually or, especially, organized in groups. In order for this to be done without disrupting the complex integration of many aspects of the workplace, computer terminals have had to be distributed to shop-floor sites so that workers could keep tabs on issues such as the flow of necessary materials to them. The computers proved effective two-way communicators in controlling quality, product specifications, and the relationships of various production units. In the influential Volvo-Kalmar experiment, they gave workers increased influence on larger systems as well as increased autonomy (Hedberg, 1975; 1980: 22-23).

29. Several papers at a recent conference on "the human side of information processing" dealt with trade unions. See especially Briefs (1980), and Docherty (1980), but also Zemanek (1980), and Kilian, Rolloy and Jonasson (1980). On speedups and increases in workloads, see Briefs (1980: 60), Mumford (1980: 102) and Eason (1980: 138).

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