University Role in the Computer Age

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Electronics has continually provided new means of facilitating human efforts. The development of radar and automatic control during World War II opened a new era in the control of machines, processes, and operations. Communication, computation, and control have merged as the means of signal encoding has become digital and semiconductor material has become pervasive in hardware. The period immediately ahead is referred to here as the computer age; my aim in this article is to describe an effective role for universities in the further development of computer electronics. To identify the university role, the evolution and projection of the computer potential are considered. Manpower, particularly scientific and technical manpower, appears to be the limiting resource in the progress of the computer revolution. Developing manpower resources is the major function of the university. This function, including the education of new professionals and the continuing education of the current work force, can bring universities and industry into a closer relationship. New forms of this relationship are discussed and projected.

Summary. Realization of the potential of computer electronics for enhanced human productivity and economic impact depends strongly on the university. New manpower and continuing education for the existing work force as well as new ideas for research and development will come from that sector. University-industry coupling offers mutual advantages to the partners and benefits to the nation in the computer age.

Evolution of the Computer Potential

Two features of computer systems are dominantly responsible for their enormous impact. First, the computer is a programmable system whose function can be designed or modified simply by changes in its program or software. This capability makes it possible to utilize a standard and volume-produced set of hardware for a wide variety of functions. It makes possible as well the customizing of function by software changes, which can be effected rapidly and economically. The second characteristic is the cost reduction of integrated circuits with time, in which each year the number of elements on a single silicon chip doubled while the cost of the chip remained essentially constant. This cost reduction has proceeded for approximately 20 years with a corresponding change in the cost of an element of nearly 1 million to one. This unprecedented increase in the capability of hardware has brought massive and inexpensive semiconductor memories, a variety of continually more powerful microprocessors, and literally thousands of applications of computer structures. Not only have simple computer structures become inexpensive, but also sophisticated ones can be applied in situations recently researched through the use of very large computers. An interesting example of this is speech generation directly from text with inexpensive, easily portable computer structures.

Areas of major impact. The major effect of computer systems on modern society has been the enhancement of human productivity. This is particularly important in view of the increasing fraction of the work force connected with the retrieval, processing, and transmission of information—precisely the functions in which computer systems offer the best opportunity for increasing the output of the individual. Over the past decade, the area of major impact has been in the industrial and commercial sectors. The importance of "smart" weapons and computer management for military systems should not be underestimated; however, over the past 5 years the Department of Defense has accounted for only about 5 percent of the total market for integrated circuits.

Applications and projections of further activity. Areas of application for computer systems are rapidly expanding and there is no evidence that saturation is being approached. Control applications range from "smart" traffic lights to automobile engine control to computer-aided manufacturing. Computer systems are already widely applied to the design and simulation of systems too complicated to study by hand, resulting in a great reduction in the number of design cycles. Thus powerful computer systems are most effectively realized by computer-designed methods. Business management is now conducted increasingly with the aid of computer systems, and programming and computer methods have become a central part of the curriculum of graduate schools of business. Sensory aids for the handicapped have improved the life of the handicapped population and, in addition, have paid off as an investment of the supporting society. The Sensory Aids Foundation of Palo Alto has competitively placed more than 250 job-ready blind people with sensory aids; their transformation from welfare recipients to taxpayers results in income tax revenue that in only a few years pays all of the costs of the sensory aids and of the services required to place and train the new wage earners, who will continue to pay taxes until retirement.

Improvements in both hardware and software will increase the impact of computer systems and their range of applications. In the hardware sphere, transducers that interface data processing and memory parts of the system with the external part of the system offer promising areas for improvement. Physical structures that respond to selected variables and are simple and economical to manufacture and reliable in operation also provide many opportunities. In the software area, higher level languages, which make the computer more easily and effectively programmed, are much in demand. However, the increased productivity of the hardware components has not been matched in the production of software, and the attention of imaginative people is being strongly directed toward this problem at present.

Requirements for realizing the computer potential. The dominant limiting

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factor to the speed of growth of computer systems is manpower. One component of the required manpower is in the technical area, in both the hardware and software aspects of the design of computer systems. A second component is in the industrial or commercial areas in which computers offer increased productivity. In a much broader sense, society must be prepared to utilize computers effectively in all aspects of life; the widespread use of computer games and the developing interest in use of the personal computer indicate progress in this direction. Research in computer systems is important on all fronts. In particular, the provision of a suitable scientific base for software and the development of more convenient user-system interfaces are urgently needed.

Manpower Resources for the Computer Age

The primary output of the university is educated people. Because of the breadth of impact of the computer, the spectrum of skills and talents required in professionals for the computer age is very broad. Those who design computer systems and adapt computers to other systems are ordinarily engineers or applied scientists. These computer professionals will be required in very large numbers over the next few years. In this rapidly changing field, the role of the gifted will continue to be significant. We should consider the source of such people and the means whereby they can be recruited for the computer and related industries.

Spectrum of required skills and talents. The technical professionals in the computer area are hardware designers, primarily designers of integrated circuits, and system designers, who are concerned with configuring hardware and software to effect the overall function required.

A fraction of the technical professionals in the computer area are concerned with research, and they play a role disproportionately large compared to their numbers. Most have doctoral degrees; they address problems where evolution of new knowledge and deeper understanding are the ends sought. Their areas of investigation include materials, conception of new devices for computing systems, hardware systems, and software systems.

A much larger manpower sector consists of the technical computer professionals who typically have B.S. or M.S. degrees. This class of individuals is in short supply. The American Electronics Association recently conducted a survey of the need for and the supply of electronics engineers and concluded that there will be a shortfall of 100,000 over the next 5-year period (*1*). In 1980 the United States produced 13,745 electrical engineers and 1,816 computer engineers at the bachelor's level. To avoid the shortfall, the output must more than triple. Other authors have pointed out the shortage of computer scientists and engineers (*2, 3*). Clearly, conventional sources must be built up, but we must find additional sources in the short term.

Finally, in every area in which computers are being adopted to increase productivity, the professionals in that area are required to learn about the computer field, its equipment, and its techniques. They need to know how to effectively utilize the problem-solving and result-presenting capabilities of computer systems. Computer courses have been included in M.B.A. programs in business schools for more than a decade. Other professions will follow this trend.

Technical computer professionals. The high value placed on a master's degree level of preparation in computer electronics has made the master's the working professional degree for electrical and computer engineering. Most of those who obtain master's degrees have an undergraduate degree in the same discipline, although this is not strictly necessary since much of the curriculum for undergraduate engineering is not directed specifically toward the subject matter of computers and electronics.

Computer technique and practice is an important component of preparation. Accordingly, cooperative education at the master's level is particularly attractive for the technical computer professional. A variety of forms of cooperative programs have evolved. One of the most successful is that at Stanford and other universities in which employees of local companies attend regular classes where the pace is set by full-time students (*4*). These classes are ordinarily televised to a plant location with a talk-back link for questions. Taking two courses per quarter, the graduate cooperative student obtains a master's degree in two calendar years. His concurrent work experience contributes heavily to the quality of education obtained.

Because the field of computer systems is rapidly changing, professionals find that only a few years after they have graduated with advanced degrees, new concepts and techniques have developed. Consequently, some form of continuing education is needed, and it is available in various forms. Short courses given by universities and by the professional societies as well as continual study of the literature, particularly in small groups of active colleagues, are effective. Both to the professional and to his employer, continuing education is an overhead that is essential for professional activity in their field.

Recruiting the gifted. Imagination, inventiveness, and productivity in developing new knowledge and understanding are attributes distributed nonuniformly over the population. Each of these attributes is found in individuals gifted in different ways; for instance, theoreticians and experimentalists are not exchangeable. Society and the individual benefit maximally when people are selected and employed in the areas in which their particular capabilities are most effectively utilized. Our society has recently made progress toward providing equal opportunities for all its members, including the disadvantaged, and continued attention to this sector must be assured. At the same time, recruitment of the gifted, particularly in new and rapidly developing areas, is an important strategy that benefits society as a whole.

In our society, the gifted or maximal performers are typically economic bargains for their employers. Unionization and government service have standardized pay scales and placed a floor below rewards for average performance. Economic and recognition incentives should be improved to stimulate the ablest. Meanwhile, recruiting the gifted to the demanding jobs in computer electronics will benefit both our world position in this sector and our overall economic productivity.

In the realm of graduate education in universities and subsequent participation in the most demanding sectors of industry, the identification, preparation, and placement of people in categories closely matching their gifts and performance profiles are important. The expected shortfall of 100,000 electronics professionals in the next 5 years cannot be made up by the pool of electrical and computer engineers and computer scientists in the United States educated through normal channels. Engineering schools must be expanded and their facilities improved. This is a critical long-term need, but efforts in this direction will not close the gap. The greatest progress will be made if additional manpower from the gifted sector is identified and obtained. Similar problems have been encountered before. During World War II, when radar and electronics were being developed for military purposes, the ablest students in science and mathematics were recruited to this normally engineering type of activity. The result of that effort was illuminating; not only were many additional people found, but their undergraduate backgrounds proved effective for their functioning in the engineering effort. In our opinion, students with high performance in undergraduate mathematics or physics or in other areas of engineering with considerable scientific content could, in 2 years, be brought to a level of knowledge and competence comparable to that of students who have continuously taken electrical engineering or computer science in undergraduate and master's programs. Clearly, the development of transition curricula and the recruitment of professionals for computer systems must be addressed vigorously.

It is interesting to assess the size of the pool of such potential computer professionals. A measure is suggested by a procedure utilized in the Electrical Engineering Department at Stanford University for the selection of a graduate population coming principally from external institutions. Performance on the quantitative part of the aptitude test of the Graduate Record Examination is one component of admissions data. Our experience has shown that, of widely used measures, this one bears the highest correlation to subsequent academic performance. The same aptitude test is taken by all applicants in engineering, mathematics, and the sciences. The upper 10 percent of electrical engineering majors scored in the 98th and 99th percentiles on this test for the last 2 years for which data are available; this pool is 445 for the 2-year period. The number of people who scored as well but in the categories of mathematics, physics, and other physical and engineering sciences for the same period was 1553 (*5*). Thus the additional pool of gifted people identified in this way is 3.5 times as large as the electrical engineering pool. Of course, many in this group will elect to remain in the pure sciences. Some can and should be drawn to attractive careers in computer electronics.

Transition curricula leading to M.S. degrees for students in this additional pool must be developed. Computer industries and universities should join in this effort. It is clear that much of the education must be done in a top-quality cooperative mode with industry, since engineering schools at present are heavily populated with a new wave of undergraduates.

Manpower production is limited by the availability of able faculty members as well as of able students. Over the past decade, universities have suffered in their competition with the electronics and computer industries for the ablest people for their faculties. The consequence is that more than 10 percent of the faculty positions in engineering in the United States are now vacant (*6*). The situation is considerably more difficult than this in the computer and electronics areas. In addition, the fraction of able American undergraduates who remain at the universities for graduate and, particularly, doctoral degrees is significantly below the desirable level. The job opportunities at the bachelor's level, coupled with the modest incremental economic rewards brought by the higher degrees, have drained off many who should have proceeded to higher degrees.

The solution to the problem of faculty shortages will be costly; it will demand investments by government, industry, and the universities. Much of American graduate education in engineering was built up after World War II by government—primarily defense—expenditures. As the defense sector has retrenched, its focus on manpower has dropped dramatically. Industry has been stressed by both problems and opportunities to satisfy its immediate manpower needs. Prospective engineering faculty have responded to the economic opportunities elsewhere. In a sense, industry's vigorous attack on its short-term problem has seriously complicated the long-term problem of providing an adequate advanced manpower base by draining off the needed university manpower to other pursuits.

A related problem for the development of manpower is the fact that experimental facilities in the universities have become inadequate. The necessary experimental facilities in computer systems, in integrated circuits, and in electronics broadly are both expensive and rapidly changing. The lifetime of capital equipment in the universities in this area is comparable to that in industry—less than 5 years. Moreover, gifts of surplus and even obsolescent equipment to the universities become white elephants rather than benefits. The rapid pace of development in this area has created an unprecedented need for investment in top-quality experimental equipment for the universities.

University-Industry Opportunities

In considering the university role, particularly in providing manpower for industry, it is important to review the development of technical education since World War II. Following World War II the federal government became the dominant factor in graduate education, and it has retained that position. The development of computers and electronics has, however, moved from the government to the industrial sector. With the growth of the computer industry, potential advantages have appeared in a strengthened industry-university connection. In a rapidly developing field communication, even between competitors, offers broad advantages, and the university is an attractive forum for that communication. Finally, industrial support for the university, facilitated by incentives to industry, offers many attractive opportunities to both the university and industry.

History of federal support for technical education. The development of radar and military electronics during World War II led to the assembly in a few locations of teams of technical people from universities who jointly brought into being the next phase of electronic development. The largest and perhaps the most influential of these centers was the Radiation Laboratory at Massachusetts Institute of Technology. The operation of that laboratory provided an object lesson on a number of points. It showed that a moderate number of gifted people can, in a very short time, provide the R & D base for new technology. It also showed, as pointed out earlier, that individuals with strong scientific backgrounds can rapidly become productive in an engineering effort. It showed dramatically that the development of ideas is stimulated by having groups of able people communicating on problems of mutual interest. It demonstrated the effectiveness of an open and flexible organization in which resources to pursue novel and worthwhile ideas are provided in a very short time.

With the end of the war effort and the dispersal of most of the accumulated manpower, a second phase of development began. Participants in the major research centers understood that what had happened there was worth preserving. Initiatives were proposed whereby the federal government would support a continuing technical effort to bring the fruits of the electronic developments to ends other than the military ones for which they had been conceived. The Radiation Laboratory at MIT was transformed into the Research Laboratory of Electronics with support from the Joint Services of the Department of Defense. New electronics centers were set up in other places. At Stanford University an electronics effort was begun by a group of people who had participated in the wartime effort in other centers. Similar centers were begun at the University of Michigan and at Johns Hopkins University. What was happening was the emergence of the federal government as the major source of support for graduate technical education in the United States. Military agencies, particularly the Office of Naval Research, understood the nature of the university system with which they were dealing. A sufficient base of support was provided and a sufficient degree of freedom for universities was preserved. The National Science Foundation emerged as a nonmilitary support base to develop graduate research and education in science for its broader purposes.

The environment was ideal for the development that was occurring. The nation was secure for a brief period in its technical supremacy. Science and engineering had had a major role in the successful defense of the United States, and this was widely recognized. A strong federal support base for American technical education developed rapidly because of conditions that existed in the late 1940's and the 1950's. The Cold War and Sputnik provided incentives to continue the technical development that had already started. At the same time, the emergence of the transistor and the computer presented a new set of objectives and opportunities. As an example of the importance of federal support, the research base in electrical engineering at Stanford and many other universities grew to a number of times the academic budget of the department.

In the first phase of this development of this university-government coupling the academic institutions were concerned that their freedom was being lost. However, the success of the federally supported educational ventures and generally farsighted administration by the governmental agencies overcame this anxiety in most cases. Some educational institutions held back, including a few with a strong private financial base. By the middle 1960's there was a new lineup of the powerful technical universities in the United States.

The space race of the 1960's accelerated technical developments in electronics and computers. In the beginning of the NASA program there was a strong emphasis on the development of manpower for the electronics industry. Similarly, the need to develop manpower for defense electronics provided a strong stimulus for support of graduate education in electronics. The Vietnam war, however, radically changed the popular perception and support of the fields of engineering. Moreover, the development of new manpower became at best an ancillary goal of Department of Defense support in the universities as R & D became the dominant goal.

The profound impact of the federal government on the nation's ability to utilize computer electronics in the industrial as well as the defense sphere is clear. No foreign government has provided such a base of support as has the United States. Our economic position in the world has benefited; in the area of advanced technology, our balance of payments is still strongly positive. At the same time, it is clear that the market for the technical manpower produced is not in the government sector but in industry. As the development of computer electronics progresses, industrial needs diverge from defense needs in quality and direction and greatly exceed defense needs in magnitude. For more than a decade the computer electronics industry, while developing an independent character and dominating the government sector in magnitude and impact, has nonetheless not developed an independent source of manpower. It has not supported the production of the manpower that it needs, nor has it sufficiently fostered university research efforts attuned principally to supporting industrial rather than governmental aims.

Advantages of the industry-university coupling. Industry is dependent on the universities in the area of manpower development. Particularly in the case of graduate technical education, the coupling of the universities and industry is important and promising. This sector of education, which requires R & D projects and expensive facilities, plays an important role for industry. The university selects and qualifies people and then transmits personnel information to prospective employers, functions that cannot be accomplished within industry itself. Expensive internal company educational programs have never achieved the same quality, breadth, or degree of acceptance as have programs in the universities leading to a recognized degree. University master's degree programs are essential in developing the manpower base, but beyond the master's degree continuing education in computer electronics is a career-long requisite. Neither industry nor the university has properly addressed this problem. Both should.

The centers of research in computers and solid-state electronics are in industry. The budget for R & D in these industries is from 5 to 10 percent of their annual sales. This number integrated over industry is many times the total budget for university research. Contact with this research base stimulates the university program in both its research and educational functions.

In the areas of semiconductors and computers, industrial parks have been built predominantly near major universities in the past two decades. In fact, the strongest university programs and the strongest industrial concentrations have proceeded together. Even universities with substantial resources from state governments or from the federal government are at a disadvantage when geographically isolated from industrial development. This has been a problem for major universities in the Midwest as computer and solid-state electronics centers have tended to appear on the two coasts. A few universities have played a key role in the proliferation of new venture industries, sustaining personnel and programs while a concept is matured to the point where independent backing enables a new venture to separate and sustain itself.

Thus in creating a graduate educational program in the area of computer electronics, universities find many advantages in connecting that educational effort to the related industry. At the same time, developing computer industries find that many functions necessary to them are most effectively carried out in the university.

Industrial support of the university. Effective as federal support of technical education has been, there is evidence for an increasing degree of bureaucracy in that support. As in other areas, this has produced visible signs of reduced effectiveness. The university would benefit significantly from a multiple support base. Private foundations, which provided that base in the past, have not grown as rapidly as education, with the result that their leavening influence is ineffective today. Industry itself needs to have a more effective voice in specifying the nature of education at the graduate level. Programs that began in an era when the major emphasis was on defense are not optimum for an industrial emphasis. In an industry where continuing education is a permanent way of life, a reliable source of such education must be ensured. Thus financial support of the university by industry offers benefits to both partners.

The 1981 tax bill provides tax credits for industries that contribute to university research programs. In the present law this provision is coupled to tax credits for increased expenditures for research in the industry itself. The coupling of the two tax credit measures dilutes the emphasis on university research support, but it is a step forward in providing a new source of university research support and a new basis for university-industry coupling.

Universities savor their independence from other institutions. Accordingly, the academic community slowly forms alliances that reduce freedom to any extent. Acceptance of the university-government relationship required a period of successful experience. At this point, industry and the university are challenged to form a mutually attractive partnership. To the extent that the university responds by selecting, preparing, and placing in industry manpower of the highest quality, American industry will be competitive in a new measure with that of any other country. With the development of a base of support from industry for this sector of education, the strength and effectiveness of American universities in the computer age will be assured.

Example of a new university-industry coupling. The addition of an industry-university relationship to an existing university-government base promises significantly stronger programs. A number of universities are building major centers for computer science and integrated circuits with industry support. Programs are under way at MIT, the University of California at Berkeley, California Institute of Technology, the Research Triangle universities, the University of Minnesota, and Stanford University. Others are being initiated. In the following paragraphs I describe the new Center for Integrated Systems at Stanford as an example of these joint industry-university initiatives.

The Center for Integrated Systems provides a graduate program, primarily in the departments of electrical engineering and computer science, with a vertical integration of technical fields spanning semiconductor physics, integrated circuits, design automation, and computer systems. Graduate students studying semiconductors have an environment with an unusual component of computer systems activity. To the computer engineer and scientist, there is a unique opportunity to participate in the design and realization of integrated systems. Experimental systems will be brought to the test and verification stage in a matter of weeks rather than months. The facilities requirements for this center are far greater than earlier requirements. Capital equipment is expected to have the same short lifetime as industrial equipment in the same field.

Industry sponsors will provide a new base of support to augment the existing research support from government sponsors. In the initial phase, the industry support will provide a new building and new programs that were not possible with government support alone. To date, 17 industrial sponsors have each pledged $750,000 over 3 years to the center. Government agencies, particularly the Defense Advanced Research Projects Agency, are investing additional funds. The industrial sponsors of the center will have access to a select and experienced pool of advanced degree candidates in computer systems. The university research program, which typically addresses long-term and speculative problems with its staff of graduate students, will provide a research output that benefits industry. Concurrently, experience with the industrial sponsors will have a directing influence on research in the university environment.

Stanford University will produce educational materials in the form of regular graduate courses, workshops dealing with special topics in computer electronics, and research reports of interest to industry. The aim of the Center for Integrated Systems is to promote American competitiveness in the technology that has become a cornerstone of our economic and technical position. The challenge to Stanford is to provide a valuable resource to industry, with services in research and manpower development that merit the industrial support. The challenge to the industrial sponsors in their multimillion dollar investment is to provide a sufficiently strong, long-term investment for the university to realize its research and manpower development goals.

References and Notes

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