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ABSTRACT

This report to the Committee on Science and Technology, United States House of Representatives, provides an analysis of how advances in computer and telecommunications technology are significantly affecting the conduct of science. The introduction describes key developments in information technology, discusses their general impact, and highlights future trends. This is followed by a chapter on the impact of information technology on scientists and research institutions and a chapter on the impact of information technology on the dissemination and use of research results. The final section focuses on the role of the federal government in this area and identifies possible questions for congressional consideration. (TW)

[COMMITTEE PRINT]

SCIENCE POLICY STUDY
BACKGROUND REPORT NO. 5

THE IMPACT OF INFORMATION TECHNOLOGY ON SCIENCE

REPORT

PREPARED BY THE

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TRANSMITTED TO THE

TASK FORCE ON SCIENCE POLICY

COMMITTEE ON SCIENCE AND TECHNOLOGY
U.S. HOUSE OF REPRESENTATIVES

NINETY-NINTH CONGRESS

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LETTER OF TRANSMITTAL

HOUSE OF REPRESENTATIVES,
COMMITTEE ON SCIENCE AND TECHNOLOGY,
Washington, DC, May 6, 1986

To the Members of the Science Policy Task Force:

We submit herewith for your information and review a background study entitled "The Impact of Information Technology on Science". This study provides a helpful discussion of this topic which was included as a separate item on our agenda under the title the "Impact on Science of the Information Age".

It is widely recognized that the burgeoning growth of a wide range of new information technologies over the last 25 years has had wide impact throughout our society including a significant, and in some cases revolutionary impact on science. It is therefore natural that, in our review of the future of our national science policy this important topic should be included as part of our study.

The present background study provides a comprehensive review of the many aspects of this topic. The background study was carried out by Ms. Jane Bortnick and Ms. Nancy R. Miller of the Congressional Research Service. It is a thorough and highly useful discussion of the many aspects of the topic.

We commend this background study to your attention, to the attention of the members of the Committee on Science and Technology, and to all members of the Congress who have an interest in this matter and in the future of America science.

MANUEL LUJAN,
Ranking Republican Member.

DON FUQUA,
Chairman.

LETTER OF SUBMITTAL

CONGRESSIONAL RESEARCH SERVICE
THE LIBRARY OF CONGRESS,
Washington, DC, July 19, 1985.

Hon. DON FUQUA,
Chairman, Committee on Science and Technology,
House of Representatives, Washington, DC.

DEAR MR. CHAIRMAN: I am pleased to submit this report entitled, "The Impact of Information Technology on Science," prepared at the request of the Committee on Science and Technology for the Task Force on Science Policy.

This report provides an analysis of how advances in computer and telecommunications technology are affecting significantly the conduct of science. The introduction describes key developments in information technology, discusses their general impact, and highlights future trends. This is followed by a chapter on the impact on information technology on scientists and research institutions and a chapter on the impact of information technology on dissemination and use of research results. The final section focuses on the role of the Federal Government in this area and identifies possible questions for congressional consideration.

The report was prepared by Jane Bortnick, Specialist in Information Science and Technology, and Nancy R. Miller, Analyst in Information Science and Technology, Science Policy Research Divsion. Production support was provided under the supervision of Ms. Shirley Williams by Ms. Sandra Burr, Ms. Karina Bush, Ms. Kaseem Hall and Ms. Christine Payne.

We hope that this report will serve the needs of the task force and appreciate the opportunity to perform this challenging assignment.

Sincerely,

GILBERT GUDE, *Director.*

CONTENTS

I. INTRODUCTION

A. Background

The Committee on Science and Technology of the U.S. House of Representatives has embarked upon a major congressional review of American science policy. The committee established a special Task Force on Science Policy for the 99th Congress to undertake a study that would identify key issues and make recommendations for the future direction of science policy. In December 1984, the Task Force published its report entitled, *An Agenda for a Study of Government Science Policy.*[1] "The Impact on Science of the information Age" was identified as one of ten agenda items the Task Force is reviewing as part of the broader science policy study.

The conduct of science is being affected significantly by an "information age" in which computers and telecommunications play an increasingly important role. As noted by the Task Force, "this may lead to new ways of doing research, research on subjects not previously explored, and may in the long run affect the content and scope of science as a whole."[2] Specifically, the Task Force identified three questions for this agenda item that warranted examination. These are:

1. How will the dissemination and use of research results be affected by the information revolution?
2. What changes affecting the individual scientist and research institutions will take place?
3. How should the Government respond to the effects of the information revolution on science?[3]

This report was prepared in response to the committee's request to the Congressional Research Service for a study that analyze these questions and look toward prospective developments and relevant future policy issues. The report focuses on how the rapid growth of information technologies—including both computers and telecommunications—has altered the way scientists conduct research and has opened up new opportunities for scientific inquiry. The impact on the individual scientist, the research institution, and the scientific community as a whole are explored with a view to future trends as well as current practices. The report also highlights major public policy questions facing our Government as a result of this changing environment and identifies areas where additional research may be valuable. While it was not possible to examine fully all aspects of this broad topic, the report attempts to

[1] U.S. Congress. House. Committee on Science and Technology. An Agenda for a Study of Government Science Policy. Report prepared by the Task Force on Science Policy. Washington, U.S. Govt. Print. Off., Dec. 1984. 62 P.
[2] Ibid., p. 36
[3] Ibid.

provide a picture of major impacts through illustrative examples of how information technology is being used in various disciplines. These examples are indicative of activities throughout the scientific community and provide some insight into the various advantages, drawbacks, and new issues brought about by the widespread employment of information technology in scientific inquiry.

B. Technological Developments

Advancements in computing and communications technologies enable today's scientist to perform some tasks more efficiently and others previously not possible. Associated work in such areas as optics further enhance the capabilities of scientific tools today. A critical element in this evolution is microelectronics. By the early 1980's the process of very large scale integration (VLSI) enabled manufacturers to produce integrated circuits containing several hundred thousand transistors on a single silicon chip. This continued miniaturization—along with decreased cost—has led to smaller and smaller computing devices that operate at faster speeds and has improved memory capacity.[4]

For more than 30 years, advances in computing technology and decreases in their costs have been dramatic. Since Von Neumann's work in the theory of electronic computers in the 1940s, computing machines have increased in speed by a factor of one billion and have become cheaper by a factor of ten million.[5] What this means is that the microcomputers of today are more powerful than the large mainframe computers of the 1950s and cost only a small percentage of their predecessors. Equally significant is the fact that this trend is expected to continue at least until 1990. If certain physicial limitations of the silicon chip eventually can be overcome, then similar improvements in performance may be expected to continue beyond that time.

These advances make possible a growing array of computers ranging from microcomputers to supercomputers (computers with the fastest central processing units and largest memories at a given time). Definitions of these categories are difficult to sustain as computing power continues to expand. For example, microcomputers have generally been described as 8 or 16-bit machines that can be used on a stand-alone basis or as intelligent terminals. However, 32-bit microcomputers are now becoming available leading to a new category called supermicrocomputers. Other new machines have earned the labels: superminis, minisupercomputers, or multis (a new class of computers "consisting of 4 to 28 modules, which include microprocessors, common memories, and input-output devices, all of which communicate through a single set of wires" [6]). What this illustrates is the rapid development of greater computing power and the increased variety of equipment available. As a result, users may select the appropriate machine for their particu-

[4] Buzbee, B.L., and D.H Sharp. Perspectives on Supercomputing. Science, v. 227, Feb. 8, 1985. p. 594.

[5] Koshland, Daniel E., Jr, The Computer Issue (editorial), Science, v. 228, Apr. 26, 1985. p. 401.

[6] Bell, C. Gordon Multis: A New Class of Multiprocessor Computers. Science, v. 228, Apr. 26, 1985. p. 463.

lar needs, may combine different machines to provide new capabilities, or may rely on one machine to perform multiple functions.

In addition, associated advances in storage devices, input and output devices, and software also are occurring. Optical disk technology may provide an effective and cost-efficient answer for storage of enormous amounts of material—both graphic and digital—because of its high density qualities. For example, "a one-sided 12-inch digital disk can store between 10,000 and 20,000 pages of text depending on fineness of resolution required. One side of an analog disk can store up to 54,000 images." [7] Improvements in higher resolution graphics terminals likewise enhance computer output capabilities and increase formats available to researchers.

Although developments in software often lag behind those in hardware, significant improvements have occurred over the last decade. Applications software is now commercially available that performs a wide range of tasks. Further, the end user—whether scientist, administrator, or consumer—is often capable of manipulating data and modifying programs without the intervention of a computer professional. A great deal more remains to be done to expand the "user friendly" qualities of software, but advances in several areas including so-called "expert systems," may prove beneficial for making systems less difficult to operate. As the costs associated with computer hardware have fallen dramatically, the software portion of systems has become more significant because of its dependence on human skills. The ability to develop advanced software may prove to be the pivotal element in future systems developments, particularly in high speed computing and artificial intelligence (AI).

Similar developments in communications technologies are providing new modes of access to scientific and technical information. Over the last 20 years significant progress has been made in the area of satellite communications. When Intelsat I was launched in 1965 it provided 249 telephone circuits *or* one television channel. The newest series of Intelsat satellites, the Intelsat VIs, will provide more than 30,000 telephone circuits *and* several television programs.[8] As in the case of computer technology, the cost per satellite circuit also has decreased dramatically over the last twenty years. Adjusted for inflation, current charges are approximately 1/18 of those in 1965.[9] Improvements in antennas, power capacity, spot beams, and broadband processing further contribute to improving satellite facilities and make possible specialized, as well as general purpose, spacecraft.

Other terrestrial technologies also enhance communications capabilities to support better information collection and dissemination activities. Key among these are advances in optical fiber technology, where lightwaves transmit digitized information through

[7] U.S. Library of Congress. The Library of Congress Optical Disk Pilot Program. Library of Congress, Washington, p. 1.

[8] Intelsat Annual Report, 1983. International Telecommunications Satellite Organization, Washington, D.C. p. 13.

[9] U.S. Congress. Senate. Committee on Foreign Relations. Subcommittee on Arms Control, Oceans, International Operations, and Environment International Communications and Information Policy. Hearings, 98th Cong., 1st Sess., Oct. 19 and 31, 1983. Washington, U.S. Govt. Print. Off., p. 147.

hair-thin glass fibers. Optical fibers offer several advantages over conventional copper wires including greater bandwidth capacity, high reliability of data transfer, greater transmission security, large repeater spacings, small size and weight, and enhanced flexibility. The TAT-8 transatlantic fiber optic cable scheduled to begin service in 1988, for example, will provide about 40,000 two-way voice channels. This compares to 48 voice channels in earlier transatlantic coaxial cable systems installed in 1955 and 1956, and to 4200 voice channels in the most recent transatlantic coaxial systems installed in 1976 and 1983.[10]

These advances in computer and communications technologies are impressive individually. However, their combined capabilities are even more significant since they open up a broad spectrum of new facilities, systems, and services. As stated in one article on the merger of information technologies:

> Information technology today involves very large-scale integrated circuits, advanced computer architectures, complex microprocessors, new ways to store data, digital communications and fiber optics, and the high-level integration of an increasing number of diverse systems. All these areas are increasingly interdependent: before long, it will be impossible to talk of one area in isolation.[11]

Telecommunications networks are being made increasingly efficient through the addition of digital switches that are computer controlled. These networks provide communications not only among machines, but also among their users. The rapid proliferation of microcomputers has enabled significantly larger numbers of scientists to connect into networks, access remote databases and computing facilities, transmit data, and communicate among each other. Increasingly distance is becoming irrelevant as communication becomes common using both local and long-haul networks. Greater possibilities for international networking may be expected as satellites and fiber optics continue to offer more channels of communication.

C. Current Impact and Future Trends

The preceding section on technological developments illustrates the substantial progress that has been made in information technology over the last few decades. Technological advancement can be expected to continue for the foreseeable future as new discoveries are made and current techniques enhanced. As impressive as this scenario is, however, the ultimate impact of information technology on all aspects of society will depend upon a host of factors that will affect its application. These include such things as social acceptance; the strength of existing practices and procedures; the adaptability of the technology to certain environments; the ease with which the technology may be employed; the support (or lack thereof) of key institutions; and the constraints of current laws and regulations.

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[10] Kogelnik, Herwig High-Speed Lightwave Transmission in Optical Fibers. Science, v. 228, May 31, 1985. p. 1044.
[11] Information Technologies Race to Merge. Electronics Week, v. 57, Sept. 24, 1984. p. 57.

In particular, policymakers both in the public and private sectors will be confronted with choices and required to make decisions that may have a significant impact on the ability of scientists and others to utilize fully the capabilities that information technology offers. Questions of funding levels, regulatory requirements, protection of intellectual property, standards setting, equity of access, and international cooperation all may warrant attention. And, decisionmakers continually may find themselves grappling with how to fashion institutional frameworks that can accommodate and support the rapid pace of technological development and its integration into various societal sectors.

The next two chapters provide significant examples of how scientists are employing information technologies in different research activities. The types of applications cover a wide range of activities. They include among other things the use of:

Computerized instruments for gathering data;
Remote terminals for accessing databases;
Computer models to simulate real life experiments;
Communications networks to link scientists;
Supercomputers to perform massive calculations; and
Expert systems for analyzing variables.

The impact of information technology is important not only because it speeds up certain analytical processes, but also because it opens up new lines of inquiry and makes new methodologies possible. And, as computing power becomes cheaper and more accessible through microprocessing, the average scientist will be able to accrue the benefits. One example of two scientists who employ a microcomputer in their daily work illustrates this. In their case they:

> . . . use an inexpensive desktop workstation to perform 48-megabit-per second data acquisition, instrument control, signal processing, statistical analysis, digital image enhancement, database storage and retrieval, and color image animation. On the same system, [he] designs and lays out printed circuit boards to control hardware used in his research, writes signal-processing algorithms, typesets research papers, and corresponds with dozens of colleagues over international electronic mail networks. One window on the screen is logged in to the Cray supercomputer at Lawrence Livermore National Laboratory for large data analysis. When their scheduled observation times at Kitt Peak National Observatory occur, [they] disconnect the workstation from the university's network, move it to the floor of the telescope, and use it to control the telescope, the image acquisition system, and image display system.[12]

Such examples as this provide an indication of what role information technology can play in scientific research. As two other scientists have stated, what exists now is only the tip of the iceberg. In their view as computing power increases, "more problems become tractable. More displays, higher resolutions, and greater in-

[12] Joy William, and John Gage. Workstations in Science. Science, v. 228, Apr. 26, 1985. p. 467.

teractivity will mean that novel ways of using the displays, such as three-dimensional . . . will become more significant. Increased sharing should lead to better management and the use of project/sharing techniques world-wide."[13]

But, will all these new capabilities become a reality for the large majority of scientists or will they be limited to a few at elite industrial or academic laboratories? And, what changes will occur in the process? American science has long held a preeminent position internationally. Will information technology serve to maintain and enhance that role or will barriers to the application of these technologies hamper our capabilities? How research funds are distributed, whether technical standards are developed, how the results of research are disseminated, and if Government policies support these activities will affect the future use of information technology in science. The stakes involved are substantial, and as a result policymakers in Congress and elsewhere have begun to address these questions.

The growing internationalization of science, as well as increasing competition from foreign countries, has heightened the awareness among policymakers and scientists of the need for state-of-the-art computer and telecommunications technologies. In addition, advances in some areas of information technology—such as certain software developments—may be considered so costly and high-risk that a Federal role may appear justified. Yet, in an atmosphere of budget austerity it may be difficult to afford all the tools research institutions and scientists request. As a result, Congress may wish to explore alternative mechanisms and approaches for providing scientists with the information technology necessary for conducting research. For example, indirect support and the involvement of the private sector may prove to be as significant as traditional funding mechanisms. Whatever the scenario, difficult trade-offs and decisions may be required as policymakers are confronted with distributing scarce resources. An understanding of the impact of information technology on science and a recognition of the issues involved will be important for making those decisions.

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[13] Gerola, Humberto and Ralph E. Gomory. Computers in Science and Technology. Early Indications. Science, v. 225, July 6, 1984. p. 17.

II. IMPACT OF INFORMATION TECHNOLOGY ON SCIENTISTS AND RESEARCH INSTITUTIONS

A. Applications of Information Technology in Science

In 1950, several years after the development of the first electronic automatic computer, scientists were not using computers on a routine basis in their research. Scientific processes—such as calculation, experimentation, recordkeeping, and documentation—were almost completely manual. The costs associated with computers as well as the difficulty in designing software limited the early use of computers in research to complex, repetitive calculations such as calculation of astronomical tables.[14]

Since that time, computers have become a valuable tool in almost all phases and fields of scientific research. Steady gains in computer processing power and memory capacity along with decreases in their costs have increased the utility of computers. In addition, improvements in programming techniques have assisted in making computers more accessible to scientists. According to an article in Science:

> Computers not only have made existing procedures easier but have led to new ones that were impossible only two decades ago. This technology . . . affects the way we think about matters ranging from funding decisions to how scientists will be able to attack new problems and, even more important, how they will change their methodologies.[15]

Today the uses of computers in science have expanded beyond their main function as calculators. Computers are used routinely for: data reduction, presentation, and pattern recognition; comparison of theory and experiment; simulation for design; and simulation for prediction.[16]

In addition, scientists employ computers to control instruments and to collect data directly from the instruments as well as analyze the data. Early applications of computers in the laboratory involved dedicated computers used with costly instruments such as X-ray diffractometers. Today, microprocessors have been incorporated into a wide range of instruments causing the distinction between separate computer and instrument to disappear.[17]

Some significant examples of the uses of computers in science include the following:

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[14] Streeter, Donald N. The Scientific Process and the Computer. New York, John Wiley and Sons, 1974. p. 14, 16.

[15] Gerola and Gomory, Computers in Science and Technology. Early Indications, p. 11.

[16] Reilly, E.D., Jr. Scientific Applications. In Encyclopedia of Computer Science and Engineering. 2d ed. New York, Van Nostrand Reinhold, 1983. p. 1302–1306.

[17] Enke, C.G. Computers in Scientific Instrumentation. Science, v. 215, Feb. 12, 1982. p. 785, 786.

As an alternative to building physical models of molecules, researchers can use the tool of computer graphics to visualize the structure of molecules in three-dimension. One recent article described a microcomputer that has enough resolution and speed to draw three-dimensional perspective views of relatively large molecules and to rotate them in space, although not in real time.[18]

Computer models have been developed which allow researchers to conduct, in simulation, the disintegration of the current West Antarctic Ice Sheet. Such modeling provides insight into how the collapse of the Earth's polar ice sheets might affect worldwide sea level.[19]

Quantum chemists rely on computers to predict properties of atoms and molecules and the dynamics of collisions between them. In many cases, quantum chemists can calculate the properties of molecules with about the same accuracy as they can be measured in experiments. Applications in numerous other areas of research have arisen, in fields such as solid-state physics and nuclear physics, inorganic and organic chemistry, catalysis, astrophysics and astrochemistry, pharmacology, biochemistry, and molecular biology.[20]

At several universities and research companies, scientists are designing computer models of biological systems, and of compounds with complex molecules, that can be used to obtain data that previously were acquired through laboratory experiments on animals.[21]

In sociology, one of the major impacts of the computer has been on the sizes of samples. A decade ago, a sample size of 1000 or 2000 was considered large; today because of the computer, major data sets have been collected with ten times as many cases. Computers also are used to simultaneously examine complex interrelations among many more variables as well as to conduct simulations of social processes. Computers thus have promoted scientific, quantitative research methods in the social sciences.[22]

Besides these applications, some researchers have incorporated one branch of artificial intelligence techniques—expert systems—into their work. For example, in the late 1960s, Edward Feigenbaum and his colleagues created the first expert system, DENDRAL (dendritic algorithm). DENDRAL deduces the structure of organic molecules from mass spectra, nuclear-magnetic-resonance data, and other kinds of information. Today, this expert system is used in organic chemistry laboratories throughout the world. Its use has led to approximately 50 publications in the chemistry liter-

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[18] Kirkland, Earl J Viewing Molecules with the Macintosh. Byte, v. 10, Feb. 1985. p. 251-252.

[19] Fastook, James L., and Terence Huges. When Ice Sheets Collapse. . . . Perspectives in Computing/IBM, v. 2, Mar. 1982. p. 4.

[20] Wilson, Stephen. Chemistry by Computer. New Scientist, v. 96, Dec. 2, 1982. p. 576.

[21] Angier, Natalie. The Electronic Guinea Pig. Discover, v. 4, Sept. 1983. p. 77.

[22] Heise, David R., and Roberta G. Simmons. Some Computer-Based Developments in Sociology. Science, v. 228, Apr. 26, 1985, p. 428, 429.

ature and has been validated by running analyses on several families of compounds.[23]

Another area of leading edge computer technology that has become increasingly critical in scientific research is large-scale scientific computing or supercomputing. Supercomputers—the fastest and most powerful computers at any given time—are used for modelling or simulating scientific and engineering problems. These high-speed "number crunchers" perform numercial calculations several times faster than the most powerful mainframe computers.

According to a 1983 report by the Federal Coordinating Council on Science, Engineering and Technology (FCCSET), fields that have been and continue to be strongly dependent on supercomputers include: nuclear weapons design; magnetic fusion energy; cryptographic analysis; aerodynamics; integrated circuit design; nuclear reactor safety; atmospheric research and weather forecasting; astrophysics; inertial confinement fusion; molecular biology and chemistry; and fundamental physics research.[24] Although most scientific computations can be performed with less powerful computers, many research problems in these fields only can be handled with large-scale scientific computers.

Scientists are at the forefront in demanding more powerful supercomputers. At a recent hearing on supercomputers held by the House Committee on Science and Technology, witnesses testified about the need for supercomputers in several areas of research. For example, one witness stated that future supercomputers will be important in the area of atomic and molecular physics with applications to the properties and design of materials. According to his testimony:

> All present supercomputers are hopelessly inadequate for solving such problems; if one learns how to solve these problems on future machines, the payoff could be spectacular. Experimental physics, chemistry, and biology have not even scratched the surface of the totality of chemical and material substances that could be industrially important. . . .[25]

Another witness described the importance of supercomputer modeling in magnetic fusion energy and energy research programs. According to his statement:

> . . . as the fusion program has advanced rapidly in the last few years . . . computational requirements for accuracy and realism have increased to the point that Cray 2 [a state-of-the-art supercomputer recently introduced by Cray Research Corporation] capabilities and beyond are required. . . . It is not possible to define a performance level that represents the ultimate capability for fusion

[23] Lenat, Douglas B. Computer Software for Intelligent Systems. Scientific American, v. 251, Sept. 1984. p. 209; and Duda, Richard O., and Edward H. Shortliffe. Expert Systems Research. Science, v. 220, Apr. 15, 1983. p. 264.

[24] U.S. Executive Office of the President. Federal Coordinating Council on Science, Engineering, and Technology (FCCSET). Report to the FCCSET Supercomputer Panel on Recommended Government Actions to Retain U.S. Leadership in Supercomputers. Washington, 1983. p. 6.

[25] U.S. Congress. House. Committee on Science and Technology. Federal Supercomputer Programs and Policies. Hearing, 99th Cong., 1st Sess., June 10, 1985. Washington, U.S. Govt. Print. Off., 1985. p. 116–117.

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> studies. . . . It is safe to assert that the fusion computing community can effectively use the best performance that the supercomputer manufacturers are capable of providing for the forseeable future.[26]

In another example, the witness described the need for a more powerful supercomputer to achieve turn-by-turn simulation of potential designs for the new Superconducting Super Collider accelerator currently in conceptual design. the integrated time needs for this application are CPU (central processing unit) times measured in Cray 1 equivalent years.[27]

During the past 30 years, computer technology has become a powerful tool for investigating scientific systems. As summarized in a *Scientific American* article:

> The introduction of the computer in science is comparatively recent. Already, however, computation is establishing a new approach to many problems. It is making possible the study of phenomena far more complex than the ones that could previously be considered, and it is changing the direction and emphasis on many fields of science. Perhaps most significant, it is introducing a new way of thinking in science . . .[28]

Similarly, the merger of computer and telecommunications technologies into networks has become an integral part of scientific research. Besides providing capabilities such as electronic mail, computer networks have further expanded the use of computers by scientists. A computer network is a collection of computers called "hosts" that can communicate with one another. A host can range from a large supercomputer to personal computer workstations. Two types of networks include local and long-haul. Computer networks increase scientific computing resources by permitting users in remote locations to access a distant computing facility. In addition, networks facilitate the sharing of programs and data and encourage collaboration among users of the network.[29] (Additional information on computer networks in science appears in section III.)

B. Impact on Scientists and Research Institutions

In many ways, the impact of computers on scientists has been positive. Computers have improved productivity of research techniques and have established new approaches to many problems. Further, advances in information technology along with decreases in costs are making the use of computers in science both feasible and affordable. For example, today, scientists can use relatively inexpensive desktop workstations to perform data acquisition, instrument control, signal processing, statistical analyses, digital image enhancement, database storage and retrieval, and color image animation. In addition, workstations can be connected with other

[26] Ibid., p. 133.
[27] Ibid., p. 137.
[28] Wolfram, Stephen. Computer Software in Science and Mathematics. Scientific American, v. 251, Sept. 1984. p. 203.
[29] Denning, Peter J. The Science of Computing: Computer Networks. American Scientist, v. 73, Mar.-Apr. 1985. p. 127.

workstations, mainframe computers, supercomputers, and remote networks.[30]

At the same time, this technology has placed new stresses on both researchers and institutions. Difficulties in areas such as funding of equipment, equal access by students and researchers, education and training, and R&D in advanced computer technology may require attention by policymakers to ensure that the maximum benefits of this technology accrue to all segments of the scientific community.

1. EVOLUTION OF THE COMPUTING ENVIRONMENT FOR RESEARCH

> The use of modern computers in scientific and engineering research spans a period of only three decades, but it has been a dynamic period in which profound changes have taken place—and clearly the end is not in sight.[31]

During the 1950s and 1960s, universities began establishing campus computing centers to support research and education. Although the institutions provided the bulk of the costs, Federal support often was the critical factor in deciding to establish or upgrade a computing facility.[32] Federal agencies also began building computing facilities. For example, the Atomic Energy Commission encouraged use of computers to manage large scale experimental facilities and data reduction in high energy physics. Other Federal entities which established computing facilities include the Department of Energy, the National Aeronautics and Space Administration (NASA), and the National Institutes of Health, as well as the scientific computing facility within the National Center for Atmospheric Research (NCAR) which was organized by the National Science Foundation (NSF).[33]

In the late 1960s, the Defense Advanced Research Projects Agency (DARPA) of the Department of Defense (DOD) implemented the first long-haul computer network. The ARPANET was a pioneering research effort into packet-switching network technology. The first host computers were those located at universities and industrial research institutions that were part of the DARPA research program in computer science. Today the ARPANET hosts over 200 computers at nearly 100 universities, Government laboratories, and private research firms. Spin-offs of ARPANET technology include commercial computer networks such as Telenet, and NSF's Computer Science Research Network (CSNET).[34]

In the 1970s, the advent of minicomputers, along with superminicomputers and microcomputers, also boosted the computing resources available to scientists. The increased availability of more affordable computing tools along with the practice of Federal agen

[30] Joy and Gage, Workstations in Science, p. 467.

[31] U.S. National Science Foundation. A National Computing Environment for Academic Research. Washington, 1983. p. 3.

[32] Ibid., pp. 3-4.

[33] Ibid., p. 4.

[34] Newell, Allen, and Robert F. Sproull. Computer Networks. Prospects for Scientists. Science, v. 215, Feb. 12, 1982. p. 846, and U.S. Executive Office of the President. FCCSET. Report to FCCSET Supercomputer Panel on Recommended Government Actions to Provide Access to Supercomputers. Washington, 1983. Appendix A.

cies not to support the full cost of computer time led to decentralization of campus computing.[35]

2. FEDERAL SUPPORT FOR INFORMATION TECHNOLOGY

By the early 1970s, computers had become a critical tool in scientific research. The Federal Government had accelerated the creation and growth of computing facilities at universities through 14 years of financial support primarily by NSF.[36] One study reviewed reports which stressed the value returned to the Nation from the 1960s NSF capital investment program. The program—which encouraged the introduction of computers into higher education by providing matching acquisition funds—had the following accomplishments:

> American research capabilities improved through the initial use of the new tool, the computer;
> Striking innovations in computing in universities led to major products such as timesharing, networks, and new architectures; and
> Wide use of computers in higher education provided qualified graduates for industry and Government.[37]

In addition to the NSF support, several Federal agencies began establishing national computing resources to support research in a specific discipline. Examples of such centers—which can be accessed from remote locations via networks—include the NSF-supported National Center for Atmospheric Research and the Energy Department's Magnetic Fusion Energy Computing Center (MFECC) at Lawrence Livermore National Laboratory (LLNL).[38]

In the early 1970s, however, NSF stopped funding academic computing and researchers began to tailor their work to the facilities available. According to the *Fourth Inventory of Computers in Higher Education* conducted during 1977, to stabilize the finances of campus computer centers, many university administrators discontinued acquiring additional computers or stopped the flow of research dollars to off-campus facilities. "Thus university computing for research entered a period of very slow growth that only recently has begun to change."[39]

A 1981 review of the four inventories of computers in higher education between 1966-67 and 1976-77 revealed that although funding for computing in all applications increased, there was a decline in Federal funding (not considering inflation or advances in computing power per dollar). While the amount of Federal funds spent on computers in higher education remained approximately the same at $80 million per year (with no corrections for inflation), the

[35] U.S. National Science Foundation. A National Computing Environment for Academic Research, p. 4.

[36] Lykos, Peter Changes in Research Computing in Higher Education. In The Fourth Inventory of Computers in Higher Education. An Interpretive Report, ed. by John W. Hamblen and Carolyn P Landis. [Hereinafter referred to as the Fourth Inventory] EDUCOM Series in Computing and Telecommunications in Higher Education. Boulder, Colo., Westview Press, 1980. p. 127.

[37] Gillespie, Robert G., and Deborah A. Dicaro. Computing and Higher Education. An Accidental Revolution. NSF Grant # SED-7823790. Washington, NSF, 1981. p. 9.

[38] Lykos, Changes in Research Computing in Higher Education, p. 143-144.

[39] Ibid., p. 127-128.

percentage of Federal support decreased form 28 percent to 7 percent. Some additional Federal investment, however, was contained in individual program budgets where minicomputers and microcomputers were part of laboratory facilities.[40]

The study also found that the fastest growing segment of computing in higher education was not for instruction or research but rather for administration. In 1981, over half of the current expenditures were for administrative purposes.[41]

Computer networks can enhance scientific research by making resources available to an increased number of scientists or by augmenting existing computer resources. A 1981 NSF report entitled "Prospectus for Computational Physics" stressed other advantages of computer networks. It noted that:

> A network provides economies of scale in software development;
>
> A network allows scientific collaborations on computational projects between participants who are physically remote from each other;
>
> A network gives the user a choice among a variety of facilities that may be more suitable to his problem than the facility he happens to be physically closest to; and
>
> A network allows researchers at smaller universities to participate on an equal basis with larger institutions.[42]

According to the Fourth Inventory, although networks have reported growth, institutions reported a small volume of use. In addition, the report stated that networks likely will never supply the bulk of computing to colleges and universities. However, even though a large percentage of computing can be performed by machines that are located on-site the remaining few percent cannot be ignored.[43]

From 1968 to 1972, NSF encouraged computer sharing by supporting the development of 25 computer networks and assisting in the expansion of others. These were general-purpose regional networks. Although some of the 25 centers still exist, many of them survived only as long as the NSF funding.[44] In 1981, NSF began supporting CSNET to serve computer science researchers, and in 1984, the agency announced plans for SCIENCENET (currently known as the NSF National Network or NSFnet) to connect the new Advanced Scientific Computing Centers.[45] In addition, NSF supports the computing facility at the NCAR. NCAR has provided computational services to the atmospheric science community for more than 20 years. Currently, the computing facility serves approximately 500 on-site users and 1500 to 2000 remote users.[46]

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[40] Gillespie and Dicaro, Computing and Higher Education, p. 16–17.
[41] Ibid., p. 3.
[42] U.S. National Science Foundation. A National Computing Environment for Academic Research, p. 15–16.
[43] Mosmann, Charles. Networks and Special Service Organizations. In the Fourth Inventory. p. 185–186.
[44] Ibid., p. 171.
[45] Barney, Clifford. CSNET Unites Computer Scientists. Electronics, v. 55, Oct. 20, 1982, p. 97-98, and telephone conversation with Dennis Jennings, NSF, 6/28/85. For additional information on the Advanced Scientific Computing Centers, see section IIC, p. 16.
[46] Telephone conversation with Gary Jensen, NCAR, Mar. 21, 1985.

Other Federal agencies also support discipline-oriented network services. For example, the Department of Energy's Los Alamos National Laboratory (LANL) Computing and Communications Division serves approximately 5,000 users in LANL and some 2000 remote users. The LANL facility primarly is used to support the nuclear weapons program. The Magnetic Fusion Energy Computer Center at LLNL provides computational services to approximately 2000 users at more than 30 remote locations. In addition, NASA plans to provide remote access to the Numerical Aerodynamic Simulator (NAS) facility which is scheduled to be fully operational by 1986. This supercomputer facility—which will be used to solve aerodynamic and fluid dynamic problems—will be available to users from NASA, DOD, other Government agencies, industry, and universities.[47]

During the 1950s and 1960s, the Government promoted and supported the growth of computing in research. In the 1970s, however, the Government reduced support for higher education computing facilities and academic facilities fell behind industrial laboratories in computing resources for research including minicomputers, workstations, etc. as well as supercomputers.[48] In the area of local facilities, the NSF Working Group on Computers for Research concluded that:

> A large gap exists between need and available support for minicomputers, attached processors, workstations, high precision graphics, local area networks and other local facilities required as part of the researchers' and graduate students' daily working environments.[49]

The Group recommended that NSF provide assistance in four areas:

> Increase support for local computing facilities;
>
> Support supercomputer services and access thereto for academic scientific and engineering research and education;
>
> Assist with the formation and use of appropriate computer communications networks; and
>
> Support academic research in advanced computer systems design and computational mathematics to improve our computational capability for solving problems beyond the reach of current supercomputers.[50]

3. RECENT UNIVERSITY/INDUSTRY RELATIONSHIPS

In recent years, there has been a trend toward expanded ties between computer manufacturers and universities. Universities—in an attempt to enhance educational and research programs—have entered into agreements with industry to obtain computer equipment at discount prices and to secure the opportunity to perform

[47] U.S. FCCSET Report to FCCSET Supercomputer Panel on Recommended Government Actions to Provide Access to Supercomputers, Appendix A.
[48] U.S. National Science Foundation. A National Computing Environment for Academic Research, p. 5.
[49] Ibid., p. 1.
[50] Ibid., p. 15.

research in computer technology. Computer companies—motivated by a desire to tap university research expertise and to increase computer applications, as well as to capture the student market under the concept of "brand loyalty"—have sought expanded cooperation with colleges and universities. In addition, companies have taken advantage of the 1981 changes in the Federal tax code which make it advantageous for firms to donate new equipment to schools, provided that the equipment is used for basic research.[51]

In a time when computers increasingly are being viewed as a valuable tool for both instruction and research, such arrangements appear to offer administrators of post-secondary institutions an attractive means of obtaining donations of computer equipment and research contracts. At the same time, some observers in universities have expressed concerns raised by these alliances to industry.

Examples of these university/industry agreements include the following:

A $35 million grant from Digital Equipment Corporation (DEC) to the University of Houston to establish a computer network that eventually will link as many as 20,000 computers in the schools four campuses and the homes of its students, 91 percent of whom commute to class.

A commitment of $50 million and two teams of specialists by International Business Machines (IBM) and Digital Equipment Corporation to the Massachusetts Institute of Technology's (MIT) Project Athena, an effort to design and build a computer network in which different terminals from the two companies can communicate; the local area network eventually may link as many as 3000 terminals.

A $20 million research contract from IBM to Carnegie-Mellon University (CMU) to develop a prototype distributed computer network to link personal workstations and a central computing facility on campus. The 1982 agreement called for the establishment of an Information Technology Center at CMU with funds, equipment, and some personnel to be supplied by IBM.

A consortium of 24 universities formed by Apple Computer Corporation to allow students to buy their own Macintoshes at about 60 percent below normal retail price; researchers at universities in the group will develop educational software for the Macintosh.[52]

Such arrangements have raised certain concerns among some university officials, faculty members, and researchers. Although the computer industry traditionally has maintained close ties to universities, in recent years, some college officials claim that the relationships have shifted. In the past, corporations funded more general research and any products were secondary. Some current research

[51] Laberis, Bill. Vendor Gifts to Universities. Better to Give or Receive? Computerworld, July 25, 1983. p. 1, 3.

[52] Gwynne, Peter Computers are Sprouting in the Groves of Academe. Technology Review, v. 87, Oct. 1984. p. 19-20; Sanger, David E. Computer Work Bends College Secrecy Rules. New York Times, Oct. 16, 1984. p. A1, D5, Sanger, David E. Wiring M.I.T. for Computers. New York Times, Feb. 17, 1984. p. D1, D3, and Carnegie-Mellon to Develop Prototype Computer Network. Perspectives in Computing/IBM, v. 2, Dec. 1982. p. 49.

contracts call for specific products which the company either will own or hold the rights to market.[53]

Another area of concern involves the academic freedom to publish results from research projects. Universities are making exceptions in some instances to prohibitions against secret research on campus to help develop products for industry. For example, according to a Carnegie-Mellon official, CMU has created barriers to the interchange of information in order to be able to use advanced equipment. The university, however, will be allowed to publish the results of their work after the company has reviewed articles to remove any proprietary data.[54] Some critics contend that this trend results in faculty members giving priority to protecting companies' trade secrets rather than promoting information dissemination. Others claim that it is a trade-off necessary to gain equipment and impartial resource.[57]

The agreements between universities and industry have raised additional concerns. A problem of equal access to equipment for all students could arise if computer companies decided to associate only with the more prestigious institutions that can best serve their technical and marketing needs. Further, if colleges become captive to a specific manufacturer, in the long run they may find themselves committed to an inadequate computer infrastructure.[56] Other issues focus on: the erosion of the educational goals of teaching and research; erosion of giving faculty members their choice of questions to pursue; and maintaining the university as a credible and impartial resource[57]

C. Status of Large-Scale Scientific Computing: A Case Study

The current debate over the status of large scale scientific computing—or supercomputing—in the United States illustrates the types of issues that policymakers may need to resolve in the future concerning the impact of information technology on science. Supercomputers are viewed as being increasingly critical to the Nation's economy and national security as well as to scientific research.

In recent years, many observers have become concerned over how to preserve U.S. leadership in supercomputing technology. Although supercomputers represent only a small segment of the computer market, the advances made in this area of leading-edge technology traditionally have been incorporated into both commercial and defense products. In scientific research, many experts claim that a growing number of problems only can be handled by state-of-the-art or future generations of supercomputers.

During the past few years, several reports by expert panels have cited problems arising from inadequate access to supercomputers by researchers and students. According to a FCCSET committee report, the leading supercomputer of the early 1970s was the Control Data Corporation 7600; however, none were installed at U.S. universities. By 1983, only three U.S. universities had on site state-

[53] Sanger, Computer Work Bends College Secrecy Rules, p. D5.
[54] Ibid., p. A1, D5.
[55] Ibid.
[56] Gwynne, Computers are Sprouting in the Groves of Academe, p. 25, 26.
[57] McCartney, Laton. Academia, Inc. Datamation, v. 29, Mar. 1983. p. 122-123.

of-the-art supercomputers.[58] Further, although Federal agencies such as NASA and DOE acquired supercomputers during the 1970s, they were used primarily for mission-oriented research. Meanwhile, colleges and universities had difficulty in maintaining existing computer facilities.[59]

Many researchers also have expressed concern over the need for expanded research and development (R&D) to produce future generations of supercomputers. In part, the calls for increased R&D have been prompted by announcements of foreign efforts in leading edge computer technology, in particular Japan's National Superspeed Computer Project. In addition, many experts claim that existing supercomputer technology has reached its limits, and that future progress will require significant advances in parallel architecture, component technology, and associated software.

Since the early 1940s, the speed of computation that can be achieved in the fastest computers available at any given time has increased by approximately seven orders of magnitude; in this decade, however, the projected performance increases available from faster components appear to be limited to at most one order of magnitude.[60] According to a recent article in *Science*, the number of users and the difficulty and range of applications have been increasing at a higher rate than the dramatic increase in computer performance. Currently, "demands for greater performance now far outstrip the improvements in hardware." As a result, difficult problems generally are undercomputed relative to scientific requirements.[61]

Concerns over the lack of access to present generation supercomputers by researchers and over competition to U.S. leadership in this technology have prompted many scientists to call for an expanded Federal role. Traditionally, the U.S. Government has provided support for supercomputers through R&D funding and procurement. For the current generation of supercomputers, the Government has stimulated development directly by purchasing or leasing a significant percentage of installed state-of-the-art machines.

One of the early advocates of an expanded Federal role was the Panel on Large Scale Computing in Science and Engineering (or the Lax Panel) sponsored by DOD and NSF in cooperation with NASA and DOE. In December 1982, the panel issued a report which recommended a federally coordinated national program to increase access for researchers to supercomputing facilities. These recommendations were based on several findings:

> The power of current and projected supercomputers was insufficient to meet existing needs in science and technology, both military and civilian.

[58] U.S. FCCSET. Report to FCCSET Supercomputer Panel on Recommended Government Actions to Provide Access to Supercomputers, p. 6.
[59] Waldrop, M. Mitchell. NSF Commits to Supercomputers. Science, v. 228, May 3, 1985. p. 568–569.
[60] U.S. FCCSET. Report to FCCSET Supercomputer Panel on Recommended Government Actions to Retain U.S. leadership in Supercomputers, p. 6.
[61] Buzbee, B.L., and D.H. Sharp. Perspectives on Supercomputing. Science, v. 227, Feb. 8, 1985 p. 591.

Important segments of the research and defense communities lacked effective access to supercomputers. At that time, with the exception of three universities and a few Government laboratories, universities and Federal research installations did not have present generation supercomputers.

Developments in supercomputing technology relied largely on the work of only two companies, Cray Research Corporation and Control Data Corporation.

U.S. leadership in supercompute. technology could be undermined by the Government's retreat from financial support of large-scale computing in universities, as well as by Japanese competition.[62]

In the summer of 1983, a NSF Working Group on Computers in Research further examined the need for greater access to supercomputers by academic scientists and engineers. After meeting with 13 scientists, the group recommended that Congress earmark funds over the next three years to install up to 10 university supercomputer centers and the telecommunications networks to link them to other schools.[63]

The Office of Science and Technology Policy (OSTP) in the Executive Office of the President also assessed the issue through FCCSET committees. In October 1983, two FCCSET committees studying Government procurement of supercomputers and supercomputer access sent their findings and recommendations to OSTP. The procurement group concluded that certain Government research programs required supercomputers with capabilities at least 200 times greater than present generation machines. To reach this objective, the group proposed that the Government provide an incentive to U.S. developers and manufacturers by guaranteeing to buy at least three of each supercomputer system that meets this capability.[64]

The FCCSET access committee determined that most researchers and students in science and engineering did not have access to state-of-the-art supercomputers and, as a result, were unable to address many current research problems. To meet immediate needs, the committee suggested that existing supercomputer center networks be expanded to serve a large number of Government-supported researchers. To meet long-term objectives, Federal agencies should design and establish new supercomputer centers and associated networks as needed.[65]

Another panel which examined the Federal role in supercomputers was the Institute of Electrical and Electronics Engineers (IEEE) Scientific Supercomputer Committee. In a report issued in October 1983, the committee determined:

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[62] U.S. National Science Foundation and Dept. of Defense. Report of the Panel on Large Scale Computing in Science and Engineering. Panel chaired by Peter D. Lax under the sponsorship of NSF and DOD in cooperation with DOE and NASA. Washington, NSF, 1982. p. 7-9.

[63] U.S. National Science Foundation. A National Computing Environment for Academic Research, p. 16-17.

[64] U.S. FCCSET Report to FCCSET Supercomputer Panel on Recommended Government Actions to Retain U.S. Leadership in Supercomputers, p. 4.

[65] U.S. FCCSET Report to the FCCSET Supercomputer Panel on Recommended Government Actions to Provide Access to Supercomputers, p. 2-4.

> Without supercomputer leadership, U.S. computer vendors will soon be at a competitive disadvantage. Further, the frontiers of science and technology often yield only to the power of a supercomputer. Finally, the applications of supercomputers to weapons design and to military intelligence . . . are critical to U.S. security.[66]

To maintain U.S. leadership in this technology, the IEEE committee suggested that the Federal Government make a commitment to scientific supercomputer development with a well defined, long-range national program. Among other measures, the panel recommended: direct funding to industry and university laboratories with advanced research programs in hardware and software; direct support to establish and operate several supercomputer centers for research, teaching, and applications development; tax incentives for supercomputer manufacturers as well as buyers and users; antitrust relief for industrial and/or university consortia; and designation of a lead organization to coordinate the roles of the Federal agencies which are dependent on supercomputer systems.[67]

Many of the concerns and recommendations made by these expert panels were reiterated at hearings held in 1983 and 1985 by the House Committee on Science and Technology.[68]

The Federal Government has responded to concerns over the status of large-scale scientific computing through several new intiatives. In response to the need for greater access by researchers and students to state-of-the-art supercomputers, NSF began work in 1984 on establishing supercomputer centers at universities. In February 1985, the NSF Office of Advanced Scientific Computing announced the selection of four institutions that will receive approximately $200 million over the next 5 years to build and operate these centers.

The institutions—University of California at San Diego, University of Illinois at Urbana-Champaign, Princeton University, and Cornell University—each will receive $7 million to $13 per year over the grant period. Each award will have a cost-sharing provision in which the States, industries, and institutions will contribute an amount that will approximately double the NSF award. Plans call for the supercomputer centers to be connected via a nationwide, high-speed network to allow researchers to communicate with the centers from any location.[69]

In 1983 and 1984, other Federal agencies received funding for new initiatives in the area of supercomputers.[70] NASA has begun

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[66] Institute of Electrical and Electronics Engineers. U.S. Activities Board. Scientific Super computer Committee Report. Washington, IEEE, 1983. p. 1.

[67] Ibid., p. 2-4.

[68] U.S. Congress. House. Committee on Science and Technology. Subcommittee on Energy Development and Applications and Subcommittee on Energy Research and Production. Computers and Their Role in Energy Research. Current Status and Future Needs. Hearings, 98th Cong., 1st Sess. Washington, U.S. Govt. Print. Off. 1983; U.S. Congress. House. Committee on Science and Technology. Supercomputers. Hearings, 98th Cong., 1st Sess. Washington, U.S. Govt. Print. Off., 1983, and U.S. Congress. House Committee on Science and Technology. Federal Supercomputer Programs and Policies. Hearing, 99th Cong., 1st Sess., Washington, U.S. Govt. Print. Off., 1985.

[69] U.S. National Science Foundation. NSF Selects Four Institutions to be National Advanced Scientific Computing Centers. NSF Release PR85-12. Washington, NSF, Feb. 26, 1985.

[70] For additional information, see U.S. Library of Congress. Congressional Research Service Supercomputers and Artificial Intelligence. Recent Federal Initiatives. Issue Brief No. IB85105, by Nancy R. Miller, June 10, 1985 (continually updated). Washington, 1985.

work on an advanced supercomputer for designing and testing commercial and military aircraft. NASA estimates the cost of the numerical aerodynamic simulator project to be approximately $120 million for FY84 to FY88.

Last year, DOE received $7 million to expand access to supercomputers for energy research scientists. Congress also approved $7 million in the energy and water development appropriations for FY 85 to establish a supercomputer center at Florida State University.

In November 1984, the National Security Agency announced the establishment of a Supercomputing Research Center. The $12 million facility will be built at the Maryland Science and Technology Center by the Institute for Defense Analyses, the contractor for the project. The goal of this endeavor is to design and produce a next generation supercomputer.

In addition, DARPA has launched the Strategic Computing Initiative (SCI). Total funding for the first five years of the program is estimated to be approximately $600 million. Although SCI will concentrate on artificial intelligence R&D, research in parallel computer architecture and advanced component performance will be important in developing future generations of supercomputers.

In 1984, a panel of U.S. experts assessed these Federal initiatives as part of a research briefing report under the supervision of the Committee on Science, Engineering, and Public Policy (COSEPUP), a joint committee of the National Academies of Sciences and Engineering and the Institute of Medicine. In their study, *Report of the Research Briefing Panel on Computer Architecture,* the panel stated:

> Several major Federal initiatives aimed at strengthening U.S. supercomputer-related capabilities have been launched and, if pursued along the strongest technical lines and with due regard for the importance of early and effective industrial involvement, can maintain U.S. computer preeminence.[71]

On the other hand, some experts have expressed concern about the imbalance in the military/civilian funding by the Government of advanced computer technology. This concern arises from the large amount of funding intended for SCI, the program which to date has received the largest amount of funding. The NSF program has been designed primarily to provide access to high-speed computing tools for the scientific and engineering community rather than to further research in advanced computing technology or work on advanced applications. Considering the importance of supercomputers and AI to the Nation's scientific and technological base, Congress may want to examine and monitor these new initiatives, as well as analyze the need for additional support for corollary research in software, applications, and computer and information sciences.

[71] National Academy of Sciences. Committee on Science, Engineering, and Public Policy. Research Briefings 1984. Report of the Research Briefing Panel on Computer Architecture. Washington, NAS, 1984. p. 14.

III. IMPACT OF INFORMATION TECHNOLOGY ON DISSEMINATION AND USE OF RESEARCH RESULTS

The growth of information technology continues to have an impact on how research results are disseminated and used by scientists. The number and breadth of databases that reference scientific findings and technical reports have grown consistently throughout the last decade, reflecting a similar growth in scientific and technical literature. In addition, computers and telecommunications are increasingly employed at selected stages of the publication process and scientists may now exchange information via electronic networks. All of these developments are important to the individual scientist in terms of access to information critical to the research process and for scientific communication. In addition, given the size of the scientific community, the amount of research conducted, and the number of scientific and technical publications produced and read each year, the use of information technology for enhancing the effectiveness of the scientific enterprise has only begun to be realized.

As the previous chapter indicated, computing capabilities have had an enormous impact on scientific advances. Similarly, research about computers has been and continues to be substantial and much progress is being made through improved electronics, computer architectures, and programs. These efforts have benefitted considerably from large Federal programs supporting computers throughout the Government. The effort devoted to employing information technology for communication, document retrieval, and database access has not been comparable. While there are selected examples in some institutions where sophisticated networking exists, there is limited funding for experimentation in the area of information retrieval and for research dealing with large scale databases and networking. This chapter thus provides through its examples an indication of the potential to be achieved were electronic information dissemination activities to be carried out on a broader basis throughout the scientific community.

A. Electronic Dissemination Activities

I. DATABASES

In 1984 more than 2,800 online databases of various types were available publicly and that number continues to grow weekly. These databases may be bibliographic in nature, contain full-text, provide numeric data, or present pictorial representations. The subjects covered range from specific disciplines to those that are multidisciplinary or problem oriented.[72] According to Professor Martha

[72] Williams, Martha E. Electronic Databases. Science, v. 228, Apr. 26, 1985. p. 445.

Williams, "scientific word-oriented databases makeup slightly more than half of the word-oriented databases offered online and more than a third of U.S. usage . . . is of the scientific databases."[73]

The American Chemical Society (ACS) was a pioneer in the development of on-line databases with its Chemical Abstracts Service (CAS). Beginning in 1961 with its Chemical Titles covering 750 journals, CAS throughout the years has added several files to its system and thousands of entries. Today CAS ONLINE includes access to CA File (bibliographic references and abstracts corresponding to documents in the printed *Chemical Abstracts* since 1967) and Registry File (records for more than six million substances cited in the printed *Chemical Abstracts* including registration numbers, CA nomenclature, and synonyms). CAS also has moved to make the full texts of several ACS journals available online and has established an international scientific and technical information network (STN International) in cooperation with Fachinformationszentrum Energie, Physik, Mathematik GmbH of West Germany. CAS is illustrative of the efforts made in other scientific disciplines (e.g. biology, engineering, physics, psychology, and medicine) to develop online databases that correspond to printed abstracting and indexing publications, and at the same time provide greatly enhanced search capabilities, more timely information, and new services.

One large database covering all fields of science is the Institute for Scientific Information's Science Citation Index (SCI). By providing references to not only the articles themselves. but also to the bibliographic citations in the articles, SCI allows researchers to identify topic relationships missed by subject indexes and to search forward in time through a given body of literature.[74] Another spinoff of SCI made possible by computer-based information retrieval techniques is citation analysis, a method that uses the number of citations to a particular paper as an indicator of its scientific significance or impact.[75] Examples of the uses of citation analysis include: evaluating the research role of individual journals, scientists, organizations, and communities; defining the relationship between journals and between journals and fields of study; measuring the impact of current research; evaluating a nation's research effort; and helping to decide the outcome of faculty promotion and tenure debates.[76]

Thus, in some quarters the ability to perform citation analysis has affected the scientific community by providing a new approach to evaluating research results. While this has proved useful in certain regards, some observers contend that citation analysis does not necessarily provide a valid measure of the quality or impact of a particular scientific journal or a researcher's work. For example, they cite the fact that SCI lists only the first author despite the fact that joint authorship has been increasing in recent years. Fur-

[73] Ibid., p. 447.
[74] Broad, William J. Librarian Turned Entrepreneur Makes Millions Off Mere Footnotes. Science, v. 202, Nov. 24, 1978. p. 853-854.
[75] Ibid., p. 856.
[76] Garfield, Eugene. Citation Indexing: Its Theory and Application in Science, Technology, and Humanities. New York, John Wiley & Sons, 1979. p. 62, and Broad, Librarian Turned Entrepreneur Makes Millions Off Mere Footnotes, p. 854.

ther, some good papers may not be referenced because they are "ahead of their time" or are "obliterated" if it is a commonly known work.[77]

Scientific numeric data are those derived from some measurement, observation, or calculation.[78] Advances in computerized measurement methods in all fields of science have led to a dramatic increase in the amount of numeric data available to scientists. This growth has placed a strain on the traditional distribution mechanisms of printed scientific literature. Further, the rising costs of publication may contribute to an increasing dependence by scientists on information technology to store, manipulate, and access numeric data.[79]

Yet, in contrast to the hundreds of scientific bibliographic databases, there are relatively few publicily available online compilations of hard scientific data for use by researchers.[80] One major scientific numeric database is the Chemical Information System (CIS), originally developed by the National Institutes of Health and operated by the Environmental Protection Agency (EPA). The system contains 20 chemical databases, including "physical and cemical properties . . . spectroscopic data . . . biological data . . . toxicological, regulatory, and environmental data, as well as an electronic mail service and linkages through the CAS Registry Numbers to bibliographic databases. . . ." [81] In November 1984, the EPA discontinued operation of the system and licensed it to two private sector firms, Fein-Marquart Associates and Information Consultants, Inc.

Several other efforts to provide scientific numeric databases also are underway. Technical Database Services currently is developing a system to supply hard data on physical, thermodynamic, transport, and other properties, and specifications for chemicals, materials, and mixtures.[82] In addition, some databases, such as the TOXICOLOGY Data Bank, operated by the National Library of Medicine, contain both text and data. In the materials area, a recent survey by the Metal Properties Council revealed some 60 online materials-properties databases in operation worldwide, although many are narrowly focused on specific classes of materials or properties.[83]

The primary Federal activity in the area of evaluated scientific numeric data has been the work of the Office of Standard Reference Data (OSRD) within the National Bureau of Standards (NBS), Department of Commerce. In 1963, OSRD established with limited funding the National Standard Reference Data System (NSRDS) to improve access by the U.S. scientific and technical community to critically evaluated numeric data on the physical and chemical

[77] Broad, Librarian Turned Entrepreneur Makes Millions Off Mere Footnotes, p. 856.
[78] Lide, David R., Jr. Critical Data for Critical Needs. Science, v. 212, June 19, 1981. p. 1343-1349.
[79] Ibid., p. 1343 and Carter, C.G. Numerical Databases. Their Vital Role in Information Science. ASIS (American Society for Information Science) Bulletin, v. 11, Feb. 1985. p. 7.
[80] Williams, Electronic Databases, p. 448. Williams notes however, that there are thousands of "in house, company restricted, and government-restricted scientific numeric databases in electronic form . . . ."
[81] Ibid.
[82] Ibid., p. 448.
[83] Bittence, John C. Property data Bases are Coming Your Way. Materials Engineering, v. 100, Aug. 1984, p. 41.

properties of substances. Public Law 90-396, the Standard Reference Data Act, passed by Congress in 1968, provided a statutory mandate for the program. Major NSRDS activities include compiling data, establishing numeric data quality standards, and operating a national standard reference data center.[84] In addition, the NSRDS program maintains various data centers, each of which has cognizance over a well-defined disciplinary area.[85] The Numerical Data Advisory Board of the National Academy of Sciences, the National Academy of Engineering, and the National Research Council provides guidance to the NBS Office of Standard Reference Data as well as other Government agencies.[86]

Although handbooks, journals, and other printed formats will continue to be a major source of scientific numeric data, computer-based formats offer several advantages: [87]

it is easier to maintain currency of a database through frequent updating;

more sophisticated search strategies are possible;

the data resulting from a search can be put into a computational program for further manipulation without the need for human transcription; and

storage and telecommunications costs are likely to decrease, while all costs associated with printed matter are likely to continue to increase.

As a result, NSRDS has initiated a program to provide data in computerized format and plans to expand this capability.[88]

There are, however, problems associated with electronic storage and dissemination such as high start-up costs and standardization. In particular, there is a need for quality assurance of the numeric data. Some experts have called for a policy similar to the one employed by NBS for its computerized databases of physical and chemical properties where documentation is provided for back up and to explain the evaluation process.[89] The concern over the quality of numeric scientific databases has led to a debate over the appropriate role of the Federal Government in this area.

According to a 1978 study by the Committee on Data Needs of the Numerical Data Advisory Board, the level of data evaluation activities is about one third to one half that needed to carry out activities planned for the next five years by Federal agencies with major mission responsibilities that require the use of reliable scientific data.[90] The study also recommended that when a particular Government mission relies heavily on results from a particular field of research, responsibility for data compilation and critical

[84] U S Dept. of Commerce. National Bureau of Standards. Technical Activities 1984. Office of Standard Reference Data. Dec. 1984. NBSIR 84-2986. p.1.

[85] Lide, Critical Data for Critical Needs, p. 1346.

[86] Luedke, James A., Jr., Gabor J. Kovacs, and John B. Fried. Numeric Data Bases and Systems. In Annual Review of Information Science and Technology, v. 12. White Plains, N.Y. Knowledge Industry Publications (for the American Society for Information Science) 1977. p. 146.

[87] Lide, Critical Data for Critical Needs, p. 1347.

[88] Lide, D. R., Jr. The U.S. National Standard Reference Data System. Computer Physics Communications, v. 33, 1984. p. 208.

[89] Lide, Critical Data for Critical Needs, p. 1348.

[90] National Academy of Sciences, Numerical Data Advisory Board, Committee on Data Needs. National Needs for Critically Evaluated Physical and Chemical Data. Washington, 1978. p. 1.

evaluation in that field should be assumed by the agency responsible for that mission, including support for the data needs of basic science by the National Science Foundation.[91]

Last year, participants at an NBS-sponsored workshop examined the impact of information technology on the generation and use of technical data as well as the barriers that must be overcome in order to realize the full benefits of these technologies. The group concluded that NBS has several roles to play, such as preparing evaluated data-bases and developing predictive models and providing leadership in establishing validation and quality control procedures for developing the format and interface standards of database management systems. Among other conclusions, the workshop determined that progress in achieving the advantages of information technology in generating, disseminating, and using scientific and technical data are limited by several factors:

> Very few validated machine-readable databases exist with broad enough coverage to meet the requirements of the relevant technical community;
>
> Scientific data, with their wide range of formats, impose special demands on database management systems;
>
> Little standardization has been achieved in the terminology for materials, chemical substances, properties, uncertainty indicators, and other data elements; and
>
> The interface between existing data dissemination systems and the working scientist or engineer is generally inefficient and hard to use.[92]

The growth in databases of all types reflects several trends that warrant future attention. A number of technological advances currently emerging may enable users to better exploit information provided in electronic databases. For example, developments in expert systems may allow for better search strategies to be employed and may reduce the need to be proficient in numerous search languages. Wide-band communications could provide for more high speed data transmission capabilities. Optical disk and video disk technology may offer a solution to high density storage problems, particularly in the case of full-text databases where there is a problem incorporating both text and graphics into one system.[93] As additional journals are prepared electronically, individual databases are created by researchers, and research is conducted using computerized instruments, it may be expected that the volume of data available in some electronic form will increase substantially. As a result, the development of standards may become more important so that equipment, data elements, and formats are compatible. In addition, traditional distinctions between different players (e.g. scientist, publisher, database vendor, equipment supplier) may become blurred. Furthermore, as scientific ac-

[91] Ibid., p. 38–39.

[92] U.S. Dept. of Commerce. National Bureau of Standards. Office of Standard Reference Data. The Effect of Computers on the Generation and Use of Technical Data. Report of a Workshop. Workshop held at NBS, Gaithersburg, Md., Mar. 19–20, 1984. Washington, NBS, 1984. p.2.

[93] Tenopir, Carol Full Text Databases. In Annual Review of Information Science and Technology, v. 19. White Plains, N.Y. Knowledge Industry Publications (for the American Society for Information Science) 1984. p. 235.

tivities involve more international cooperation and access to foreign data becomes more critical to scientific research, the character of databases may become increasingly international in scope.

2. COMPUTER/TELECOMMUNICATIONS NETWORKS

Networking is now a key component in disseminating information, exchanging data, and accessing resources in parts of the scientific community. Combined computer and communications capabilities make possible a wide array of services that support scientific research and provide access to information and colleagues on a global basis. As stated in chapter II, networks are important because they connect both computers and the users of those systems. A number of major networks already have been described, including the ARPANET operated by the Department of Defense that hosts over 200 computers at various academic, Government, and industry sites.

While networks are of major concern to scientists requiring access to computing facilities, they are important as well for their role in disseminating research results and enhancing communication among researchers. Major commercial long-haul networks, such as Telenet, play a key role as avenues for accessing the major scientific databases offered by database vendors in the United States and abroad. A number of specialized networks focused on specific scientific endeavors also are emerging, such as the NSF-supported CSNET that serves the computer science community.

The ability of scientists to communicate electronically also is increasing as local area network technologies are improving and becoming more cost effective. These local networks may then be linked to larger networks that operate nationally or internationally. Perhaps the most advanced system is at IBM's research facility at Yorktown, New York where researchers are tied into a worldwide network that links them with IBM offices around the world. "The services include electronic mail, file forwarding, and a directory of users."[94]

Electronic mail has become a major attribute of networks—whether local or long-haul—currently used by scientists. In fact, "the value of electronic mail came as a surprise to the developers of ARPANET, who had expected the network to be used principally for computer-to-computer communication for resource sharing but found instead that the dominant use was mail."[95] While electronic mail systems are becoming more prevalent and popular among scientists, the systems often are still awkward to use and have limited capabilities. Improvements in software and communications protocols may make these systems easier to operate, but it is doubtful that they will supplant some of the fundamental modes of scientific communications, such as conferences and person-to-person consultation.

Several examples exist of how computer/communications networks have provided opportunities for scientists to advance their research and give a broader community of researchers access to the

[94] Gerola and Gomory, Computers in Science and Technology. Early Indications, p. 14.
[95] Newell and Sproull, Computer Networks: Prospects for Scientists, p. 848.

latest data. For example, a system called MOSIS has been developed at the University of Southern California to allow fabrication of experimental integrated circuits using the ARPANET. In this case:

> MOSIS uses the network to allow a great many designers to share access to fabrication. . . . With MOSIS, the user communicates directly with . . . remote files and systems to monitor his progress and check the correctness of the proceedings. The speed and accuracy of the responses far exceeds anything he could get through a human intermediary on a routine basis.[96]

In another illustration, the PROPHET system was developed by the National Institutes of Health "to support the needs of research pharmacologists and others working in chemical and biological interactions." [97] The system:

> Provides facilities for maintaining files of chemical structures, experimental results, and laboratory notes and has computational tools for reformatting data, analyzing data, and preparing graphical presentations and so on. The users of the system may share data files and may use simple electronic mail and bulletin board tools to communicate . . . The PHOPHET working environment has fostered some intense collaborations, such as experiments undertaken by three geographically separated groups in the pharmacology, crystallographic structure, and animal testing of a single chemical compound.[98]

What these examples show is that while computing power or communications capabilities independently offer considerable support to researchers, the combination of the two can potentially offer new ways of approaching problems.

Another area where experiments in scientific communication have been occurring is in computer conferencing. Experiments in computer conferencing among scientists were begun in the mid-1970s, partially with support by the National Science Foundation.[99] There are numerous computer conferencing systems now available—both public and private. Computer conferencing offers several advantages, including that participants may be geographically dispersed and can participate at any number of levels as they desire. In addition:

> The participants can scan titles of entries and read only those that appear interesting or important. Responses can be edited and changed at a participant's discretion. Participants do not have to wait in line to speak, and they are never interrupted or otherwise prevented from expressing their views. Because all entries and responses are typed and saved in a computer file, all the conference proceed-

[96] Ibid., p. 849-850.
[97] Ibid., p. 850.
[98] Ibid.
[99] For an in-depth discussion of computer conferencing see. Kerr, E.B., and Hiltz, S.R. Computer-Mediated Communication System. New York, Academic Press, 1982.

ings are immediately available to be typeset and published by traditional means if desired.[100]

Computer conferences, however, have certain limitations. Generally they have been somewhat difficult to operate, particularly for the novice or occasional user. In addition, the quality of the information exchanged by the participants has sometimes been called into question and has proved to be a major inhibiting factor for future participation. An evaluation of one recent international computer conferencing experiment among scientists revealed that while a large percentage indicated their willingness to participate in future conferences, they also found several shortcomings in the system. Specifically:

> These scientists were concerned about the lack of contribution by others, the quality of the information that was presented, and the lack of focus or direction to the conference. They saw little of value contributed by others, but were also reluctant to contribute themselves to such an open conference.[101]

3. ELECTRONIC PUBLISHING

The use of computer technology in publishing continues to increase as publishers explore the potential for distributing material more quickly and for providing new electronic information services. While there is definitely a trend toward using computers more in various stages of the publication process, the arrival of the totally electronic scientific publication is not yet here.

In the late 1970s King Research prepared a study for the National Science Foundation on "Statistical Indicators of Scientific and Technical Communication." [102] Included in that work was a description of an "electronic alternative" to publishing scientific papers through paper-based journals. King described the various phases of the publication process where computers would be integrated, including "sophisticated text-editing systems" for authors, "joint writing of text through teleconferencing systems," electronic transmission of the manuscript in digital form to the publisher, electronic editing, and online peer review of the article. The article could then be distributed electronically in several forms ranging from the printed version to bibliographic references to full-text available online. King also identified constraints on such a system coming into being, both technological (e.g. standards) and economic (loss of revenues from subscriptions).[103]

Since that time the major factor influencing electronic publication of scientific and technical papers has been the rapid growth of microcomputers and word processors. This allows an increasing number of scientists to prepare their manuscripts in digital form. In some instances, these articles are then sent to the publisher in

[100] Tombaugh, Jo W. Evaluation of an International Scientific Computer Based Conference. Journal of Social Issues, v. 40, 1984. p.130.
[101] Ibid., p. 129.
[102] King, Donald W., Dennis D. McDonald, Nancy K. Roderer. Scientific Journals in the United States. Their Production, Use, and Economics. Hutchinson Ross Publishing Co., Stroudsburg, Pa. 1981. 319 p.
[103] Ibid., p. 308-312.

electronic form; in others it is necessary for the publisher to re-key the information into that firm's system. The Association of American Publishers estimates that "the proportion of scientific and technical documents done with computers has increased from about 35 percent in 1980 to 60 percent [in 1984]."[104]

Thus it appears that while publishers are using computers more in the editing and composition stages of publication and authors increasingly are employing personal computers and word processors in preparation of manuscripts, the linkage between the two is far from complete. Some of the problems involved are technological in nature. "A major problem lies in the incompatibility of various systems."[105] Another is the requirement of many scientists for certain "special" characters, such as mathematical symbols. In addition, there is a lack of standardization identifying the different parts of a document. "Generalized tagging will identify the structural parts of the manuscript—title, chapters, abstract, headings and footnotes—in such a manner that those parts of the text can be manipulated to produce several products, including a printed document."[106]

Publishers also are addressing some of the problems inherent in electronic publication and are experimenting with various approaches. The American Chemical Society (ACS) now offers the full text of 18 of its research journals online using Bibliographic Retrieval Services (BRS). BRS also is working with Elsevier Science Publishers to produce several scientific journals dealing with pharmacology and toxicology online. ACS saw several advantages for making their journals available online. These include:

> currency (the file was updated every two weeks);
> immediate access to the full article; and
> the ability to search the full text rather than only title words and index terms.[107]

At the same time, a number of problems remain for electronic publishing. At present there are technological limitations to providing graphic along with textual material. Some experimentation is occurring using videodisks containing related graphics to complement the text. Further developments in optical disk technology may offer a more effective solution to this problem. As previously mentioned, the lack of "standardized languages and the incompatibility of hardware and software among different systems" remains a major hurdle for electronic publishing to overcome.[108] Several legal and economic issues remain as well. Copyright concerns have been expressed consistently by producers of databases because of the increasing ease of downloading information onto a microcomputer and subsequently using it in other forms or for additional purposes for which producers will not be compensated. There is also some concern about the effect of electronic dissemination of

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[104] Case, Donald Electronic Submission of Manuscripts. The Academic Author's Viewpoint. In 1984· Challenges to an Information Society, Proceedings of the 47th ASIS Annual Meeting, v. 21, 1984. p. 177.
[105] Ibid.
[106] Ibid., p. 178.
[107] Terrant, Seldon W Publishing Scientific Information. Chemical and Engineering News, Apr. 25, 1983. p. 54.
[108] Ibid., p. 55.

journal articles on scientific and technical journal subscriptions. According to one source, "now that Chemical Abstracts Service, which prints abstracts of research papers and patents is offered electronically, the number of customers not renewing their subscriptions to the printed journal has doubled."[109]

Another aspect that is of particular concern to the scientific community is the problem of peer review in electronic publishing. One firm, Comtex Scientific Corp., several years ago proposed a system cf online acces to both research data and abstracts. Their approach was not to have the material peer-reviewed, but rather to base inclusion upon acceptance by an editorial board comprised of experts in various scientific fields.[110] The willingness of scientists to accept data that has not been peer reviewed has not been demonstrated. In fact, in the computer conferencing systems described in the previous section, the lack of peer review was cited as a major shortcoming of this approach to exchanging information and "publishing" research results. According to one study, "a lack of prestige for entering information in a conference can be attributed in part to the fact that submissions are not subjected to any kind of peer review or editing to insure their accuracy."[111] It appears that some mechanism for providing peer review—perhaps by electronically distributing the information to experts for review—will need to be established before the advantages of electronic publishing may be fully realized.

B. Impact of Electronic Dissemination Activities

1. FEDERAL SUPPORT

The importance of disseminating scientific and technical information in support of scientific research has long been recognized by the Federal Government. When the National Science Foundation was created in 1950, the exchange of scientific information was identified as an important aspect of the agency's mission. Following the launch of Sputnik I, the important role of science was emphasized by policymakers concerned with the U.S. position vis-a-vis the Soviet Union. As a result, in the later 1950s and the 1960s several new entities were created, legislation was passed, and studies were conducted that focused on national science policy and the importance of scientific and technical information dissemination. These included: the establishment of a Science Information Council; the creation of an Office of Science Information Service in NSF; the preparation of the so-called Baker, Crawford, Weinberg, Greenberger, and SATCOM reports on science information activities; the establishment of the Committee on Scientific and Technical Information (COSATI) to coordinate the science information programs throughout the Federal Government; and later, the establishment of the Office of Science and Technology Policy.[112]

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[109] Publishers Go Electronic, Business Week, June 11, 1984. p. 85.
[110] Terrant, Publishing Scientific Information, p. 54.
[111] Tombaugh, Evaluation of an International Scientific ComputerBased Conference, p. 142.
[112] For an in-depth description of early scientific and technical information activities in the Federal Government see. U.S. Congress. House. Committee on Science and Technology. Scientific and Technical Information (STI) Activities: Issues and Opportunities. Prepared by the Con-

Continued

Scientific and technical information (STI) activities continued to expand throughout the decades of the 1960s and 1970s, although policy attention to this topic began to decrease by the 1970s. According to the National Science Foundation, between 1960 and 1978 federally funded STI activities increased almost seven times.[113] While scientific and technical information continued to be considered an important activity, broader information policy issues began to receive greater attention within the Federal Government. In 1971 COSATI moved from the Executive Office of the President to the National Science Foundation with NSF's Office of Science Information Service taking on administrative responsibilities and providing staff. COSATI subsequently was abolished one year later. In 1977, NSF's external Task Force on Science Information Activities recommended changes in the agency's role in science information and information science. Based upon those recommendations, the Office of Science Information Service was restructured as the Division of Information Science and Technology (DIST). The focus of DIST is on supporting research on information as a science rather than on science information.[114]

As advances in information technology made possible new techniques for collecting, storing, and disseminating information, new Federal activities were undertaken to take advantage of these techniques. The National Science Foundation supported some of the early efforts in developing bibliographic databases for the sciences, such as the Chemical Abstracts Service. These activities were sponsored primarily by technical societies and as they moved into operational stages and as the private sector began to recognize the market potential for database services, the role for the Government in providing direct support diminished.

Several mission-oriented Federal agencies began to employ computers for creating online access to their bibliographic databases in the early 1970s. In 1971 the National Library of Medicine's online retrieval system, MEDLINE (MEDLARS On-Line), became operational offering access to numerous databases covering international literature in the health sciences. MEDLARS (Medical Literature Analysis and Retrieval System) has continued to grow throughout the years, adding new files and additional bibliographic references from around the world. Beginning in the late 1960's, DOE began developing an online retrieval system for energy information. From the computerized system today, *Energy Research Abstracts,* a number of specialized printed indexes, and online access to almost five million citations in various energy fields are provided to the DOE community. In addition, the major Energy Data Base is available to the public via commercial online vendors. The DOE system was developed from work on systems done by Lockheed for NASA

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gressional Research Service, Library of Congress. Washington, U.S. Govt. Print. Off. 95th Cong. 2d Sess. Dec. 1978. p. 18-23 and U.S. Congress. Senate. Committee on Labor and Public Welfare. Federal Management of Scientific and Technical Information (STINFO) Activities. The Role of the National Science Foundation. Washington, U.S. Govt. Print. Off. 94th Cong. 2d Sess. Feb. 1976. 103 p.

[113] U.S. National Science Foundation. Federal Funds for Research, Development, and Other Scientific Activities. Fiscal years 1976, 1977, and 1978. v. XXVI. NSF 78-300. Washington, U.S. Govt. Print. Off. p. 42.

[114] U.S. Congress. House. Committee on Science and Technology. Scientific and Technical Information (STI) Activities: Issues and Opportunities. p. 20-22.

which also resulted in NASA's online system and the commercial spin-off of Lockheed Dialog online bibliographic retrieval service. The DOE, NLM, NASA, and DOD online systems together represent availability to well over 90 percent of the results of Federally sponsored R&D.

The major Government entity providing public access to a broad range of scientific and technical information is the National Technical Information Service (NTIS) in the Department of Commerce. NTIS sells to the public U.S. Government-sponsored research, development, and engineering reports, in addition to foreign technical literature and other reports prepared by contractors for national and local government. Like MEDLARS, NTIS's database of bibliographic references is available online through commercial database vendors. NTIS is unique, however, in that it is self-supporting, relying upon income from sales rather than from an annual congressional appropriation.

While Government agencies have been successful in applying information technology to their scientific and technical information activities, they also have increasingly been confronted with the need to justify their roles in the face of budget constraints, an active private sector information industry, national security controls on sensitive data, and Government policies that favor reductions in Government information dissemination activities. At the same time, there are efforts underway to improve Government scientific and technical databases by increasing the amount of foreign data and improving the validity of numeric data. Both of these are areas in which there has been a call for increased Federal support. These issues will be discussed more fully in the next chapter on the Federal role.

2. PRODUCTIVITY

The role of information in fostering scientific inquiry is well recognized. As stated by Dr. Lewis Branscomb, Chief Scientist of IBM:

> When accurate, pertinent data are available, work can proceed. When they are not, work must stop while a researcher invents a different approach, develops (or redevelops) missing data, or experimentally verifies unevaluated data reported in the literature before daring to commit another period of time and effort on a project that is heading down a critical path.[115]

Despite the recognition of scientific and technical information's critical place in the research undertaking, it has been difficult to provide quantitative assessments to reflect this. In part, this is due to the fact that the flow of information is such an integral component of the research environment; consequently it is difficult to isolate its contribution. Further the economic value of information is extremely difficult to estimate, because it may change depending upon a variety of factors (e.g. user needs or timeliness). As a result,

[115] Branscomb, Lewis M. Improving R&D Productivity. The Federal Role. Science, v. 222, Oct. 14, 1983. p. 133.

little hard data on the value of STI exist to demonstrate what is widely acknowledged in the scientific community.

Despite these limitations, however, certain anecdotal material reflects the contribution made by accurate and timely information to scientific advancement. In addition, the Department of Energy (DOE) commissioned a study by King Research, entitled "Value of the Energy Data Base" to demonstrate how the availability of energy information contributed to the productivity of scientists working in energy-related fields.

The King Research study surveyed DOE-funded scientists and engineers to illustrate how their reading of scientific and technical literature led to savings of time and/or equipment. Based upon the savings reported by those surveyed, the study concluded that approximately $13 billion could be estimated in future savings to DOE scientists. According to King Research,

> this suggests that an investment of $5.3 billion [DOE's R&D budget] in the generation of information and about $500 million [DOE's information processing and dissemination budget] in processing and using information yields a partial return of about $13 billion in terms of savings to scientists and engineers in their time and in equipment.[116]

Although the specific methodology employed and dollar amounts cited may be debated, the study provides considerable evidence that the availability of relevant information to scientists and engineers increases productivity in the R&D environment by eliminating duplication of experiments and avoiding unnecessary costs. The result is that researchers may then pursue more effective research directions and channel scarce resources in the most profitable way.

Other examples exist of how database searches in comparison with manual search techniques may reduce the amount of time required to find needed information. As one illustration demonstrates, it may take only 10 to 15 minutes to search 20 years of *Chemical Abstracts* whereas:

> Those who have done manual searching know that one would be hard pressed to pull 20 years of *Chemical Abstracts* index volumes off the shelf in 10 minutes, let alone look up just one compound and list the numbers of the references that refer to the compound and read the abstracts.[117]

In 1983 the National Academy of Science's Numerical Data Advisory Board, the Committee on Science and Technology of the U.S. House of Representatives, and the Congressional Research Service cosponsored a workshop entitled, "Towards a National S&T Data Policy." At that workshop numerous representatives of industry, government, and academia discussed the importance of scientific and technical data for solving research questions and the appropriate role of the U.S. Government.[118] Among the examples offered

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[116] U.S. Dept. of Energy. King Research, Inc. Value of the Energy Data Base. U.S. Dept. of Energy, Mar. 31, 1982. p. 1.

[117] Williams, Electronic Databases. p. 445

[118] National Academy of Sciences. Numerical Data Advisory Board, and U.S. Congress. House. Committee on Science and Technology. Towards A National S&T Data Policy (collected presentations at a workshop, Apr. 14, 1983) Washington, NDAB [1983]. 129 p.

well several by Dr. Hollis Caswell, Laboratory Director, IBM Corporation. In one case, Dr. Caswell stated that in trying to solve memory errors in computer systems, researchers discovered that nuclear particles on semiconductors were at fault. The availability of a symposium paper on this topic "saved the computer industry much effort since, once the problem was identified, solutions evolved rapidly." [119]

In another case, William F. Brown, Jr. a consultant to NASA gave a list of hardware failures traceable to inadequate databases. He also cited the situation where the test failure of a rocket motor case resulted in a $17 million loss and the cancellation of that portion of the program. He commented that:

> The motor case was fabricated from a relatively new steel using improper welding methods. The information that these methods were unsuitable was at the time not widely disseminated but available in the Aerospace Structural Metals Handbook sponsored by the Air Force. The cost of preparing the Handbook Chapter for this steel was about $3000 or 0.02 percent of the loss.[120]

The above illustrations provide good examples of how access to scientific and technical data can streamline the research enterprise, save time, allow for more efficient use of resources, avoid costly mistakes, and improve industrial productivity. When one looks to the future, however, the importance of access to critical scientific and technical databases takes on an even broader scope. As more and more data are gathered, the ability to organize those data in meaningful ways becomes more essential. The combination of new computing techniques with the growth of new data offer researchers the capability of probing scientific problems in new ways. This trend is illustrated by a recent report, *Models for Biomedical Research: A New Perspective* prepared by the National Academy of Sciences on request by the National Institutes of Health.[121]

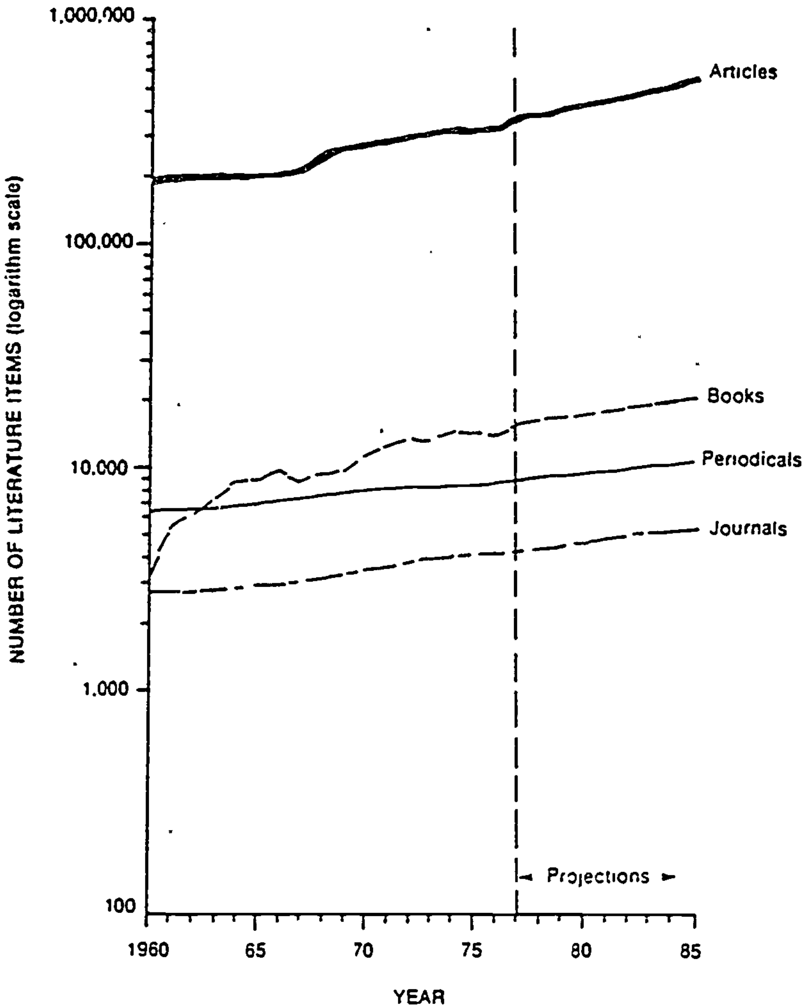
The report recommends the development of a "biology-wide information system—a computerized 'matrix data base'—structured so that it can be accessed from a multitude of dimensions." As a result, "the database would vastly expand the array of possible models used by making available information on phenomena that are analagous to various aspects of the subject under study." [122] The impact of information being made available by this method could open up whole new fields of inquiry previously untapped. But, at the same time, researchers may need to understand information technology as well as their own field of study to take full advantage of the opportunities afforded by new information dissemination techniques. How such skills and training will be incorporated into the graduate education framework is an issue that may acquire growing importance in the future.

[119] Ibid., p. 20.
[120] Ibid., p. 62-63.
[121] Holden, Constance. An Omnifarious Data Bank for Biology? Science, v. 228, June 21, 1985. p. 1412.
[122] Ibid.

3. SCIENTIFIC COMMUNICATION

As the number of scientists and engineers has grown over the last several decades, the scientific and technical literature has grown concomitantly. The table below illustrates the growth of scientific and technical literature between 1960 and 1985.[123]

[123] King, Donald W., et. al. Scientific Journals in the United States. p. 22.



Number of literature items published, 1960–1985.

Another interesting measure of scientific communication is the quantity of U.S. research publications as a proportion of world publications in leading journals. In 1982, U.S. scientists and engineers accounted for 35 percent of the world S&T literature, although U.S. scientists comprise only about 15 percent of the world's scientists.[124] Since 1973, however, the U.S. proportion of the world's S&T literature has decreased in all fields except for biomedicine, while other countries' proportion has increased.[125]

At the same time, the number of S&T publications with joint authors from different countries has increased.

> More than 42 percent of all multiple-authored publications in mathematics were internationally collaborative efforts in 1980, and over 30 percent of the joint publications in the fields of physics and earth and space sciences were also internationally coauthored.[126]

The growing internationalization of science is exhibited as well by the number of U.S. publications that cite foreign documents. That number has increased in the last decade so that by 1980 "44 percent of all citations found in U.S. publications were attributed to foreign publications." [127]

Assessing the impact of information technology on this situation raises a number of issues. For one, the increased demand for access to foreign scientific and technical literature in U.S. databases is well understood in an environment where foreign S&T activities are becoming more substantial and international cooperation more prevalent. In addition, international competition in high technology industries has heightened the awareness about the value of foreign scientific and technical information. A report prepared by the Congressional Research Service for the House Science and Technology Committee, *The Availability of Japanese Scientific and Technical Information in the United States,* analyzed issues raised at the committee's hearings on that topic.[128] The report found that:

> Japan's efforts to coordinate STI activities both domestically and internationally have outpaced similar efforts in the United States. Given the significant strides made in Japanese science and technology, a number of individuals feel that the United States needs to reverse that situation to remain competitive.[129]

Another key element that merits attention is the role that information technology may have in altering and improving traditional forms of scientific communications. Several examples have been given previously in this chapter showing how computer/communi-

[124] U.S. National Science Foundation. Directorate for Scientific, Technological, and International Affairs. Division of Science Resources Studies. International Science and Technology Data Update, Jan. 1985. p. 23.

[125] Ibid.

[126] U.S. National Science Foundation. National Science Board. Science Indicators 1982. Report of the National Science Board 1983. p. 29.

[127] Ibid., p. 31.

[128] U.S. House. Committee on Science and Technology. The Availability of Japanese Scientific and Technical Information in the United States. Report prepared by the Congressional Research Service, Library of Congress for the Subcommittee on Science, Research, and Technology, 98th Cong., 2d Sess., Nov. 1984. Washington, U.S. Govt. Print. Off. 1984. 29 p.

[129] Ibid., p. 1.

cations networks are now being employed in scientific research. Some experts maintain that electronic communications may replace older forms of interaction among scientists—such as personal communication, meetings, and reading publications. Most authorities contend, however, that the new approaches will augment rather than replace more traditional communications with the scientific community.

In some cases, electronic networking among scientists has been a very profitable experience. According to one scientist, "the ability of a newtwork to knit together the members of a sprawling community has proved to be the most powerful way of fostering scientific advancement yet discovered." [130] Other scientists have found that the value of communications networks is dependent upon the type of scientific activity involved. Two managers at IBM research facilities studied the relative importance of computing power, display capabilities, and communications for scientists involved in basic research, engineering, and management. They found that for scientists performing basic research, "the existence of an electronic linkage, powerful though it may seem, has not, in fact, altered the traditional methods of scientific work." [131] They found that for engineers, where greater collaboration on projects is commonplace, electronic communications have proved to be more useful. Finally, they concluded that electronic communications has the greatest value for managers who are responsible for coordinating and executing numerous projects.[132] While the study at IBM reflects only one research environment, it is instructive for identifying what trends are evolving in the application of computer technology. It may also serve as a starting point for future research in this area.

The role of information technology in improving scientific and technical communication is recognized increasingly by the scientific community. *Frontiers in Science and Technology: A Selected Outlook,* (the third volume in the series of five-year outlooks for science and technology mandated by the National Science and Technology Policy, Organization and Priorities Act of 1976) identified "the importance to scientific and engineering progress of the effective use of new communications technologies" as one of its major themes.[133] The report cited the "intensifying pace of scientific advance and the increasing importance of basic research to gestating new technologies", along with "the increasingly interdisciplinary nature of many fields of science and technology" as major reasons to "exploit to the fullest the new communication modes now becoming available." [134] The report concluded that the development of sound public policies in this area will depend upon further careful examination of the issues involved.[135]

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[130] Denning, The Science of Computing: Computer Networks, p. 127.
[131] Gerola and Gomory, Computers in Science and Technology: Early Indications, p. 16.
[132] Ibid., p. 17.
[133] Frontiers in Science and Technology. A Selected Outlook. A report prepared by the Committee on Science, Engineering, and Public Policy of the National Academy of Sciences, National Academy of Engineering, and Institute of Medicine. W.H. Freeman and Company, New York. 1983. p. 7.
[134] Ibid., p. 9.
[135] Ibid., p. 10.

IV. ROLE OF THE FEDERAL GOVERNMENT

Continuing advances in computers and telecommunications and decreases in their costs will make possible a growing role for information technology in scientific research. For example, the proliferation of affordable and more powerful microcomputers as well as less expensive broad bandwidth telecommunications channels could enable large numbers of scientists and students to incorporate information technology into their work. To date, the Federal Government has supported information technology in science through mechanisms such as funding for R&D in information technology, funding for purchase of information technology equipment, tax credits for donations of equipment, and funding of database development.

In the future, however, the Government may need to consider alternatives or additional support to supply scientists with access to information technology necessary for their research. For example, potential difficulties in extending the limits of existing technology may require increased Federal support so that scientists can have access to state-of-the-art computer and telecommunications technologies. Further, with today's emphasis on Federal budget austerity and reliance on the private sector, many organizations and universities may not be able to afford the information technology or data critical to their work. Other issues that policymakers may want to consider include: the impact of international competition in information technology; the need for access to and dissemination of domestic and foreign STI; and the need for coordinated national policies for both scientific and technical information and information technology development.

The following sections outline some of the issues that could arise in a debate over the appropriate role of Government in the area of information technology in science.

A. Federal Support Mechanisms

The Federal Government has supported the development and use of computer and telecommunications technologies in science through: R&D funding for information technology; funding of information technology equipment for research; funding for database development; and procurement of information technology.

Historically, the Federal Government has been a major sponsor of the Nation's R&D effort in information technology. Within the Government, the Department of Defense has been a principal player. For example, according to a recent report by the Office of Technology Assessment, in FY84 the Government supplied $933 million in basic and applied R&D funding for the areas of computer science and electrical engineering. Among Federal agencies, the Defense Department was the largest supporter of information technology R&D; estimates of the proportion of DOD funding ranged from 70 to 80 percent or more of all Federal funding.[136] Further, many of the information technology R&D projects funded by DOD—such as the packet-switching network technology of the ARPANET—have evolved into commercially successful applications.

The Federal Government also has supplied funding for universities and researchers to purchase information technology equipment or to provide access to information technology. From 1957 to 1972, NSF played an important role in this area by improving the capacity and capability of computing facilities as well as providing access to computers. During this period, NSF awarded grants to help initiate and expand computing facilities for education and research at colleges and universities. After 1972, NSF discontinued this program and began supporting services through individual research grants. Without Federal support for computing facilities, academic facilities fell behind industrial facilities in computing resources for research.[137] For example, a recent NSF survey indicated a lack of modern equipment in computer science. According to *Academic Research Equipment in the Physical and Computer Sciences and Engineering,* 91 percent of the department and research facility heads in the computer sciences stated that they were unable to perform critical experiments because of a lack of needed equipment.[138]

Another area of Federal support has been funding for database development. The Government sponsored early database development by professional societies through NSF funding, but eliminated this support as these endeavors became commercially viable. The Government also sponsored creation of databases within Federal agencies, such as the National Library of Medicine's MEDLARS system. But systems such as these have come under increasing criticism by private entrepreneurs who believe the Government unfairly competes with private sector efforts. The Government also has supplied funding for equipment and personnel to develop databases as a component of research grants.

Another area of Federal support has been the work of the Office of Standard Reference Data in the National Bureau of Standards in developing evaluated numeric databases in the physical sciences. There appears to be a growing demand for access to data and facts rather than strictly bibliographic citations. This offers a major challenge for the technical and information communities. In a number of workshops on developing national online numeric data systems, particularly in the materials area, the appropriate roles of government, industry, and the academic and technical societies have been debated. There seems to be a consensus in the technical community that there is a need for Government support in seeding the development of technology demonstration projects for online

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[136] U.S. Congress. Office of Technology Assessment. Information Technology R&D: Critical Trends and Issues. Washington, U.S. Govt. Print. Off., 1985. p. 29, 294.

[137] U.S. National Science Foundation. A National Computing Environment for Academic Research, p. 5, 11.

[138] U.S. National Science Foundation. Academic Research Equipment in the Physical and Computer Sciences and Engineering. [Prepared by Westat, Inc., under NSF Contract No. SRS-8017873] Washington, NSF, 1984. p. 6.

data access as well as in undertaking data evaluation.[138A] In addition, the Government has supported R&D for "user friendly" systems as an aid in online searching. Current Federal support of R&D in artificial intelligence and expert systems may facilitate the search process in the future.

In the area of procurement, the Government is the Nation's largest ADP user. In FY85, the Government plans to spend almost $14 billion on Federal information systems and technology. Further, that budget is projected to increase at a rate faster than that of the overall Federal budget.[139] Federal support through procurement is particularly important in providing a market for supercomputer manufacturers. For example, within the United States, the Department of Energy is the largest user of supercomputers with a total of 22 systems currently installed.[140]

The Government also has supported private sector R&D in information technology through indirect means such as tax credits for R&D costs, increased deductions for manufacturer's donations of new R&D equipment to universities, and modifications of antitrust liability for cooperative research activities.

The United States generally is considered preeminent in computer and telecommunications technology. However, given the importance of information technology to the Nation's science infrastructure, some observers feel that existing forms of Federal support may not be adequate to extend the limits of current technology, to respond to challenges from foreign competitiors, and to provide access for all researchers. They also claim that the private sector may not be in a position to expand R&D initiatives to the level necessary to maintain U.S. leadership in information technology. Conversely, others claim that the current mechanisms of support are adequate and that any expanded support may only be necessary in specific areas such as those that are high risk or are in the national interest.

In addition, certain aspects of the current structure of Federal support have raised a number of issues. For example, the large amount of funding intended for the Strategic Computing Initiative significantly increases the Defense Advance Research Projects Agency's dominance over the direction of the Nation's advanced computer research efforts. This increase in funding has led some observers to express concern about a potential imbalance in military/civilian funding for information technology. Another issue focuses on the impact of Federal funding cuts for information technology equipment for research. According to the findings in *A Na-*

[138A] J.H. Westbrook and J.R. Rumble, Jr., Eds., "Computerized Materials Data Systems" Proceedings of a Workshop (1982). Available from the Office of Standard Reference Data, National Bureau of Standards, Gaithersburg, MD 20899.

J Rumble and T Northrup, Eds. "Computerized Materials Data—A Workshop for Ground Vehicle Engineering," (Society of Automotive Engineering, Warrendale, PA 1984).

J Rumble and J.H Westbrook, Eds. "Computerizing Materials Data—A Workshop for the Nuclear Power Industry" NBS Special Publication 689. U.S. Dept. of Commerce, National Bureau of Standards, 1985, 37 pages.

National Academy of Sciences. Numerical Data Advisory Board; and U.S. Congress. House. Committee on Science and Technology. Towards a National S&T Data Policy (collected presentations at a workshop, Apr. 14, 1983) Washington, NDAB [1983]. 129 p.

[139] U.S. Office of Management and Budget. Management of Federal Information Resources (Draft OMB circular). Federal Register, v. 50, Mar. 15, 1985. p. 10736.

[140] U.S. Congress. House. Committee on Science and Technology. Federal Supercomputer Programs and Policies, p. 25.

tional Computing Environment for Academic Research, since the early 1970s, ". . . the United States has not provided the wide variety of computing services its academic scientists need to keep them in step with modern technology." [141] Other issues include: the need for expanded Federal support of databases; the role of the Federal Government in the area of procurement; and the effectiveness of measures providing indirect Federal support.

Possible Questions for Congressional Consideration

Is the existing pluralistic structure of Federal support for information technology sufficient to achieve advances in information technology and maintain U.S. preeminence?

Should the Defense Department continue as the predominant source of Federal funding for information technology R&D or should a non-defense agency assume more responsibility in this area to shift the imbalance in military/civilian funding?

Are the current Federal initiatives aimed at strengthening the Nation's advanced computer technology—such as DOD's Strategic Computing Initiative and NSF's supercomputer center program—sufficient to maintain U.S. leadership in information technology? If not, how should they be restructured?

Should NSF provide funding for work on advanced applications of supercomputers in addition to supplying access to supercomputer centers?

How has the discontinuance of NSF grants for computing facilities at colleges and universities affected scientific research? Besides such support as university supercomputer centers, CSNET, and the proposed NSF National Network, what other role, if any, should NSF be playing in the area of funding for or providing access to information technology equipment?

What effect, if any, will DOD's University Research Initiative have on funding for information technology equipment and facilities? What has been the impact of university/industry agreements to acquire as well as develop information technology resources?

Should the Federal Government increase support for access to the existing STI knowledge base and if so, how should this support be structured? Should Federal assistance be directed toward specific disciplines such as numeric databases for a particular scientific field, toward technological developments such as expert systems to facilitate the online searching process, and/or toward experimental systems?

What has been the impact of Federal Government procurement of computers and telecommunications on advances in information technology? In the area of high-risk

[141] U.S. National Science Foundation, A National Computing Environment for Academic Research, p. 15.

R&D, such as advanced supercomputers, should the Government guarantee a market for new designs to foster innovation in the private sector?

What has been the impact of indirect Federal measures—such as the Economic Recovery Tax Act of 1981 and the National Cooperative Research Act of 1984—on private sector R&D in information technology? Should the Government place greater emphasis on these types of support mechanisms for information technology as a means of fostering a greater degree of private sector initiative?

B. International Competition

Foreign nations increasingly are viewing expenditures in R&D as critical to their economic growth and productivity. In particular, foreign governments are promoting funding of R&D in information technology. Recent targeted national programs by foreign governments highlight the importance attached to this area for future competitiveness in world markets.

The most highly publicized foreign efforts are two Japanese programs—the National Superspeed Computer Project and the Fifth Generation Computer Project. These programs are designed not only to meet future domestic needs in large-scale computing and AI, but also to enable Japan to gain access to international markets for these products. The Japanese National Superspeed Computer Project is a ten-year cooperative effort between the Ministry of International Trade and Industry (MITI) and six major Japanese computer vendors. By the end of the project in 1990, MITI plans to supply one-half of the total $200 million funding. Work on Japan's ten-year Fifth Generation Computer Project began in 1982. Like the supercomputer project, this program is a joint endeaver between MITI and private companies. Although total funding for the life of the project is not publicly stated, some sources estimate that up to one billion dollars may be spent. The Japanese Government has supplied seed money and staffing; from 1982 to 1984, the Government provided approximately $40 million in funding.[142]

Other foreign efforts in information technology include Great Britain's Alvey Program for Advanced Information Technology, and the European Community's (EC) ESPRIT (European Strategic Program for Research in Information Technology) project and RACE (Research on Advanced Communications technologies for Europe) program. In 1983, the British Government announced the five-year Advanced Information Technology program, which concentrates on AI as well as very large-scale integrated circuits, software engineering, and man/machine interfaces. The Government will provide $310 million for the program while private industry is expected to supply an additional $230 million. Last year, the EC authorized one billion dollars for the ten-year ESPRIT project. Research will emphasize advanced microelectronics, software technology, advanced information processing, office automation, and computer integrated manufacturing. The project is a cooperative effort

[142] U.S. Library of Congress. Congressional Research Service, Supercomputers and Artificial Intelligence: Recent Federal Initiatives, p. 3–4.

between private companies, universities, and research institutes. The EC will provide $126 million in matching grants in 1985 and $150 million in 1986 for research projects. In 1985, the EC approved the first stage of the proposed RACE program to develop a Europe-wide integrated broadband telecommunications network. EC members and participating companies are each expected to contribute one-half of the estimated $30 million funding for the first stage of the project which focuses on pilot research projects. If the pilot phase is successful, total spending on RACE could reach $650 million over its ten-year lifetime.[143]

The United States generally is recognized as the leader in information technology. Recent Federal initiatives in advanced computer technology, such as the Strategic Computing Initiative, attest to the Government's interest in maintaining this leadership position. Yet, given the current environment of increased international competition, some observers claim that the United States needs to expand efforts to monitor developments in information technology and to acquire related STI on any advances to remain competitive. They assert that the United States can no longer afford to neglect foreign competitors—in particular Japan—in the areas of computer and telecommunications technologies.

For example, last year a panel of experts examining foreign efforts in supercomputer technologies concluded that "It is quite important for U.S. activities aimed at maintaining awareness of Japanese technical developments through suitable translations be accelerated, possibly through programs undertaken by NSF or DARPA."[144] In addition, hearings have been held by the House Science and Technology Subcommittee on Science, Research and Technology on access to Japanese STI in the United States. Witnesses described a number of coordinated efforts in Japan to monitor and acquire U.S. technology and scientific and technical data; these efforts have outpaced comparable efforts in the United States.

Some experts claim that a need exists for monitoring foreign developments in information technology and acquiring related literature. They assert that for some nations such as Japan there are significant barriers that require the U.S. Government to play a greater role in accessing and disseminating these data. For example, in the area of Japanese STI, a significant barrier is the lack of qualified technical translators caused in part by the lack of appropriate emphasis on Japanese language programs at U.S. universities. To overcome this barrier, the U.S. Government may consider increasing support for Japanese language programs in universities and providing financial aid to science and engineering students who study Japanese.

On the other hand, some observers claim that the need for greater access to and dissemination of foreign STI has not been demonstrated. Further, if the demand exists, the argument can be made to let the marketplace respond to the need. Some have likened the

[143] Ibid.; Dickson, David. Europeans RACE to Close Telecommunications Gap. Science, v. 227, Mar. 29, 1985. p. 2259, and Europeans RACE toward EC-Wide Telecommunications System. Communications Daily, v. 5, Apr. 4, 1985. p. 6.

[144] Committee on Science, Engineering, and Public Policy, Research Briefings 1984. Report of the Research Briefing Panel on Computer Architecture, p. 16.

current debate over Japanese STI to the U.S. reaction to Russian STI in the post Sputnik years. During that time, many argued for increased Federal efforts to translate Soviet technical literature and to teach scientists and engineers the Russian language. Yet today, the scientific community pays little more attention to the Soviet literature than it does to that of any other country.

In addition, there are concerns that U.S. producers of database services are being unfairly kept out of foreign markets. Foreign barriers, such as unequal telecommunications costs, unique standards, and preferences for domestic systems and services inhibit U.S. firms from expanding into foreign markets.[145] Recent efforts at the Organization for Economic Cooperation and Development (OECD) to adopt a "Declaration on Transborder Data Flows" may prove beneficial to reducing these barriers. In that declaration, member countries agreed to: (1) cooperate on promoting access to data and information and avoid creating unjustified barriers to the international exchange of data and information; (2) seek transparency in regulations and policies relating to transborder data flows; and (3) develop common approaches for dealing with issues related to transborder data flows.[146]

Despite such progress, however, some observers believe that the U.S. Government may need to be more vigilant in negotiating a reduction in barriers to transborder data flows so that both U.S. enterprises and international scientific cooperation may be strengthened.

Possible Questions for Congressional Consideration

With the recent announcements of foreign targeted programs in information technology, should the United States Government seek to cooperate in these efforts as a means of reducing research costs and increasing access to information on foreign developments?

Should the Federal Government assume a larger role in efforts to promote advances in information technology to respond to challenges from foreign competitors?

Is there a demonstrated need for increased access to foreign STI? If so, should the Government assume a greater role to overcome any existing barriers such as the shortage of competent technical translators in certain languages? How has the private sector responded to the demand for foreign STI?

Should the Government identify foreign languages that have an inadequate supply of qualified technical translators and increase support through funding of university language programs or financial aid for students in science and engineering who undertake foreign language study?

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[145] U.S. Congress. Committee on Foreign Relations. International Telecommunications and Information Policy: Selected Issues for the 1980s. A report prepared by the Congressional Research Service of the Library of Congress. 98th Cong., 1st sess. Sept. 1983, S. Prt. 98-94. Washington, U.S. Govt. Print. Off., 1983. p. 21-25.

[146] Organization for Economic Cooperation and Development. Committee for Information, Computer and Communications Policy Declaration on Transborder Data Flows. Paris, OECD. Mar. 27, 1985.

Should the Government increase support for bilateral scientific and technical agreements to promote exchanges of researchers and information?

Should the Government implement a coordinated program for STI networks similar to efforts by the Japan Information Center for Science and Technology?

What steps should the Government take to insure that the international flow of STI is not hampered by foreign market barriers?

C. Access and Dissemination

Information technology is proving to have both positive and negative effects on assuring access to scientific and technical information. On the one hand, communications networks enable researchers around the world to acquire needed information from remote databases. On the other, some scientists may find it too costly to acquire current computing capabilities or may be limited by their lack of knowledge of information systems. Several other policy questions also have an impact upon access to scientific and technical information. These include issues of national security control, conflicts between public and private sector information producers, and growing budgetary constraints.

In recent years, a number of laws, regulations, and Government policies have increased controls over the dissemination of sensitive scientific and technical information. For example, the Department of Defense Authorization Act for Fiscal Year 1984 (10 U.S.C. 140c) gave the Secretary of Defense the authority to withhold DOD technical data having military or space applications if such data could not be exported lawfully without approval or license under the Export Administration Act or the Arms Export Control Act.[147] While it is widely recognized that maintaining national security is of the highest priority, there is growing concern over how to achieve the appropriate balance between national security and the open exchange of scientific information.

Some critics charge that the Government gives away valuable scientific and technical data through its publicly available databases. Others maintain, however, that open scientific communication provides the best means of ensuring technological advances that can provide for national security. Of concern to some is the growing amount of scientific and technical material that potentially could be restricted from public dissemination. This may prove to be a growing problem for Government producers of scientific and technical databases. The Department of Defense has attempted to clarify the situation by stating that "fundamental" research conducted at universities and Federal laboratories that was not classified would not be restricted. DOD defines fundamental research in terms of four factors: performer, budget category, sponsoring DOD

[147] For an in-depth analysis of this issue see: U.S. Library of Congress. Congressional Research Service. National Security Controls and Scientific Information. Issue Brief No. IB82083, by Relyea, Harold C., June 26, 1985 (continually updated). Washington, 1985; and Relyea, Harold C., ed. Striking A Balance: National Security and Scientific Freedom-First Discussions. American Associaton for the Advancement of Science, Committee on Scientific Freedom and Responsibility, Washington, May 1985.

entity, and special contractual provisions.[148] Despite these efforts, the scientific community remains concerned about the possible impact of controls on scientific communication. This concern has been heightened by the growing proportion of the Federal R&D budget designated for defense and space-related efforts.

On another front, Government electronic dissemination activities are being confronted with the growth of private sector services and reductions in Government budgets. Some private sector vendors have charged that Government providers of databases have an unfair advantage because their dissemination services are subsidized by Federal funding. They maintain that because Government agencies do not need to make a profit on their dissemination activities, their prices undercut those of private information providers and force them out of business.[149]

On the other hand, supporters of Government database activities worry that public access to critical information will be limited to only those who can afford it; only databases that are profitable will remain available; and information required by agencies to perform their missions will be diminished. A report by the National Commission on Libraries and Information Science Panel on the Information Policy Implications of Archiving Satellite Data found that "a number of basic research programs would be placed in a precarious position if Landsat [remote sensing] data on which they rely were to be priced beyond their ability to purchase without Government support." [150]

The issue of public versus private database providers has received attention both by the executive and legislative branches and remains a major topic of debàte today.[151] It has been highlighted recently by the growing budget constraints faced by all Federal agencies. One result of these budget reductions is that agencies are being forced to seek reimbursement from their data and systems users to offset costs involved. This approach has been reemphasized by the recent OMB circular on management of Federal information resources, issued December 12, 1985.[152] The circular revises and consolidates several existing circulars and attempts to provide a broad framework for Government-wide information management activities. Although the circular acknowledges the importance of "open and efficient exchange of government scientific and technical information" for scientific advancement, it also includes provisions that may limit dissemination activities.[153]

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[148] U.S. Dept. of Defense. Publication of the Results of DOD Sponsored Fundamental Research. DeLauer, Richard D. Undersecretary for Research and Engineering, Oct. 1, 1984.

[149] The National Library of Medicine's MEDLARS system has been the focus of much of this debate. See: Holden, Constance. Library of Medicine Versus Private Enterprise. Science, v. 212, June 5, 1981. p. 1125.

[150] U.S. National Commission on Libraries and Information Science. Panel on the Information Policy Implications of Archiving Satellite Data. To Preserve the Sense of Earth from Space. Washington, NCLIS, 1984. p. 17.

[151] U.S. National Commission on Libraries and Information Science. Public Sector/Private Sector Interaction in Providing Information Services. Washington, NCLIS, 1982. 83 p.

[152] Executive Office of the President. Office of Management and Budget, Management of Federal Information Resources, Circular No. A-130, Dec. 12, 1985. For an in-depth analysis of the draft circular see: Relyea, Harold C., et. al. Management of Federal Information Resources: A General Critique of the March 1985 OMB Draft Circular—Matters for Possible Congressional Consideration. Congressional Research Service. July 5, 1985. 42 p.

[153] OMB Circular A-130, p. 4.

Of particular concern to government database producers are the sections of the circular that deal with dissemination of information and with cost effectiveness. The circular directs agencies to:

> Disseminate such information products and services as are: (a) specifically required by law; or (b) necessary for the proper performance of agency functions provided that the latter do not duplicate similar products or services that are or would otherwise be provided by other government or private sector organizations.[154]

Another provision conditions dissemination activities on a number of factors, including the recovery of costs, where appropriate, through user charges.[155] The implications of directives such as these for providers and users of Government scientific and technical information have yet to be fully analyzed. They do raise concerns, however, that agencies may be forced to reduce their information dissemination activities and that certain users will be unable to afford growing information fees.

Possible Questions for Congressional Consideration

Should the Government provide mechanisms for ensuring that all scientists have access to information technology and databases necessary for their research?

What efforts should be made to facilitate the training of scientists in all disciplines in the use of information technology?

What effect will increased national security controls have on dissemination of scientific and technical information through publicly available Government databases?

What has been the impact of national security controls on international cooperation in science?

What would be the impact of a policy proposed by some Federal officials that would restrict access to Soviet bloc scientists to the NSF supercomputer centers?

What criteria should be established to delineate the appropriate role of the Government versus the private sector in developing databases and related services and more broadly, in providing access to the results of federally sponsored R&D?

If certain government scientific and technical information activities are eliminated as a result of budget constraints and administration policies, will the private sector be willing or able to provide them? What guarantees could be established to provide continuity for services even if they cease to be profitable?

Given demands on allocating scarce Federal dollars, how will Federal agencies determine the cost effectiveness of their information dissemination activities given the difficulties associated with assigning value to information?

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[154] Ibid., p. 5.
[155] Ibid.

What would be the impact of a significant reduction in Federal STI management activities.

Who will determine if agency missions are being accomplished and the public is being served under the new OMB information resources management circular?

What will be the impact on users if charges for access to Government information services increase substantially?

D. Government Information Policymaking

One recurring topic in debates over the role of the Federal Government in scientific and technical information activities and information technology development is the concept of a Government focal point for policymaking. Supporters of such an entity believe it could perform both a coordinating role for Government information collection and dissemination activities and a centralized policymaking role. Numerous reports have been written about the importance of coordinating the various agency activities for collecting and disseminating scientific and technical information. Proponents of establishing some coordinating entity believe it could lead to less duplication, enhanced accessibility, and more comprehensive information systems.[156]

There are others, however, who believe that the creation of a new Government entity may only add another layer of bureaucracy. These experts contend that the diversity of players better reflects the fact that information systems are an integral part of all Government programs and therefore are best addressed within the context of an agency's mission. They maintain that existing Government agencies—such as the Office of Management and Budget (OBM) and the Office of Science and Technology Policy (OSTP)—are able to perform the necessary coordinating function.[157]

The Paperwork Reduction Act of 1980 (P.L. 96-511) significantly enhanced OMB's role in managing Government information activities. Based upon the Act's mandate, OMB has sought to reduce duplicative information gathering and dissemination activities and promote greater efficiency in the use of information technology. Congress has expressed its concern that OMB has not devoted sufficient resources to adquately accomplish these objectives.[158] In addition, the emphasis in the recent OMB information management circular on reducing dissemination activities Government-wide and on cost recovery has raised additional concerns within the information community about OMB's desire to provide effective coordination and support for critical information activities.[159]

The National Science and Technology Policy, Organization, and Priorities Act of 1976 (P.L. 94-282) established the Office of Science

[156] U.S Congress. House. Committee on Science and Technology. Scientific and Technical Information (STI) Activities: Issues and Opportunities, p. 18-27.

[157] U.S. Congress. House Committee on Science and Technology. The Information Science and Technology Act of 1981 Report prepared by the Congressional Research Service, Library of Congress for the Subcommittee on Science, Research, and Technology, Committee on Science and Technology. 97th Cong., 2d Sess., Washington, U.S. Govt. Print. Off., June 1982. p. 33.

[158] U.S. Congress. Senate. Committee on Governmental Affairs. Paperwork Reduction Act Amendments of 1984, Report to accompany S. 2433. U.S. Govt. Print. Off., Washington, Aug. 6, 1984. p. 6.

[159] Relyea, Harold, et. al Management of Federal Information Resources A General Critique of the March 1985 OMB Draft Circular.

and Technology Policy in the Executive Office of the President. Among the functions assigned to OSTP was the requirement to:

> Consider needs for improvement in existing systems for handling scientific and technical information on a Government-wide basis, including consideration of the appropriate role to be played by the private sector in the dissemination of such information.[160]

The above responsibility is only one of several references to scientific and technical information in the Act.[161] While OSTP maintains that it has fullfilled its responsibilities in this area, critics disagree. They maintain that OSTP's lack of attention is a reflection of the general disinterest of high level policymakers within the Government to scientific and technical information issues. These observers contend that since the abolition of COSATI and the restructuring of NSF's science information function, no Government entity exists that focuses on critical issues affecting scientific and technical information.[162]

Claims of lack of coordination in information policy formulation, however, go beyond t[illegible] issue of Government scientific and technical information activ[illegible]s. The range of information policy issues is considerable and may include such diverse subjects as intellectual property, standards, or privacy. While there is agreement that the pronouncement of a single national information policy is neither feasible or desirable, there is concern that the United States needs to establish a more consistent and comprehensive approach to information policymaking. This has been emphasized by the fact that information technology is becoming increasingly important for both the Nation's economy and the national defense. In addition, the recognition of the contribution of scientific and technical advancement to the U.S. position internationally has prompted renewed attention to STI as an essential element to be considered in broader policy development.

Congress and the executive branch are faced not only with addressing how the Government can effectively support information activities, but moreover, how it can promote private sector investment in new technologies and database development. The establishment of an appropriate Government role in this area requires the balancing of many interests. Whether the current Government policymaking framework is adequate to acheive this goal remains a question. Traditionally, there has been opposition to creating any type of "information czar" in whom total authority for information policy would be vested. Various proposals, however, have been made for restructuring Government information policy functions.[163] While there is no agreement on the optimal organization-

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[160] P.L. 94-282, The National Science and Technology Policy, Organization and Priorities Act of 1976, Title III.

[161] Mitre Corp. Metrek Division. Scientific and Technical Information. Options for National Action, McLean, Va. Mitre Corp., 1976, p. 22.

[162] U.S. Congress. House. Committee on Science and Technology. The Information Science and Technology Act of 1981, p. 24.

[163] In the 99th Congress, H.R. 744, The Information Science and Technology Act of 1985, was introduced to establish an Institute for Information Policy and Research and to create a Special Assistant for Information Technology and Science Information in OSTP. In addition, S. 786, The

al arrangement, there is a strong belief—in parts of Government and the private sector—that the United States might benefit from a more coherent and coordinated approach to information policymaking and from greater resources devoted to this effort.

Possible Questions for Congressional Consideration

Should some type of coordinating entity be established in the Executive Branch to ensure that scientific and technical information activities are not duplicative, are comprehensive, and are meeting the needs of our research enterprise?

Should Congress conduct additional oversight of both OSTP and OMB to assess the adequacy of their actions in the scientific and technical information area?

What mechanisms can be established to enhance the interaction between Government and the private sector in information activities? What policies should be adopted to promote private sector endeavors?

Given the broad range of issues involved in information policy, should some focal point be established for Government policymaking? Or, should additional resources be committed to existing entities so that they can perform such a function more effectively?

Information Age Commission Act of 1985, was introduced to establish an Information Age Commission comprised of public and private sector members as a forum for assessing the impact of computer and communications systems on the Nation and its citizens. Neither bill has received congressional action.

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