Chapter 1

Introduction and Overview Observations

The Office of Technology Assessment is conducting an assessment of the effects of new information technologies—including high performance computing, data networking, and mass data archiving-on research and development. This background paper offers a midcourse view of the issues and discusses their implications for current discussions about Federal supercomputer initiatives and legislative initiatives concerning a national data communication network.

Our observations to date emphasize the critical importance of advanced information technology to research and development in the United States, the interconnection of these technologies into a national system (and, as a result, the tighter coupling of policy choices regarding them), and the need for immediate and coordinated Federal action to bring into being an advanced information technology infrastructure to support U.S. research, engineering, and education.

RESEARCH AND INFORMATION TECHNOLOGY—A FUTURE SCENARIO

Within the next decade, the desks and laboratory benches of most scientists and engineers will be entry points to a complex electronic web of information technologies, resources and information services, connected together by high-speed data communication networks (see figure 1-1). These technologies will be critical to pursuing research in most fields. Through powerful workstation computers on their desks, researchers will access a wide variety of resources, such as:

- an interconnected assortment of local campus, State and regional, national, and even international data communication networks that link users worldwide;
- specialized and general-purpose computers including supercomputers, minisupercomputers, mainframes, and a wide variety of special architectures tailored to specific applications;
- collections of application programs and software tools to help users find, modify, or develop programs to support their research;
- archival storage systems that contain specialized research databases;
- experimental apparatus-such as telescopes, environmental monitoring devices, seismographs, and so on---designed to be set-up and operated remotely;
- services that support scientific communication, including electronic mail, computer conferencing systems, bulletin boards, and electronic journals;
- a "digital library" containing reference material, books, journals, pictures, sound recordings, films, software, and other types of information in electronic form; and
- specialized output facilities for displaying the results of experiments or calculations in more readily understandable and visualizable ways.

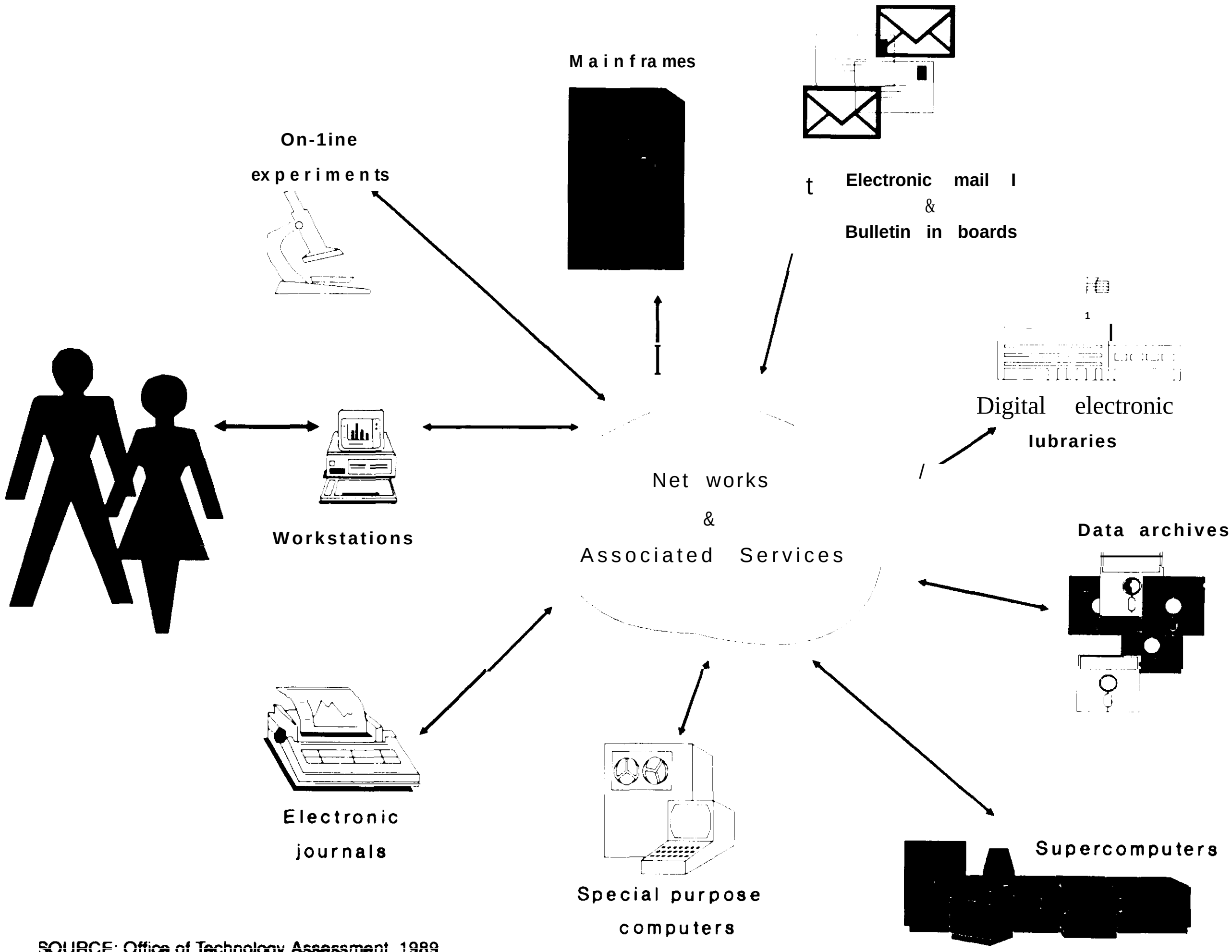
Many of these resources are already used in some form by some scientists. Thus, the scenario that is drawn is a straightforward extension of current usage. Its importance for the scientific community and for government policy stems from three trends: 1) the rapidly and continually increasing capability of the technologies; 2) the integration of these technologies into what we will refer to as an "information infrastructure"; and 3) the diffusion of information technology into the work of most scientific disciplines.

Few scientists would use all the resources and facilities listed, at least on a daily basis; and the particular choice of resources eventually made available on the network will depend on how the tastes and needs of research users evolve. However, the basic form, high-speed data networks connecting user workstations with a worldwide assortment of information technologies and services, is becoming a crucial foundation for scientific research in most disciplines.

MAJOR ISSUES AND PROBLEMS

Developing this system to its full potential will require considerable thought and effort on the part of government at all levels, industry, research institutions, and the scientific community, itself, It will present policy makers with some difficult questions and decisions.

Figure I-I—An Information Infrastructure for Research



SOURCE: Office of Technology Assessment, 1989.

Scientific applications are very demanding on technological capability. A substantial R&D component will need to accompany programs intended to advance R&D use of information technology. To realize the potential benefits of this new infrastructure, research users need advances in such areas as:

- more powerful computer designs;
- more powerful and efficient computational techniques and software; overly high-speed switched data communications;
- improved technologies for visualizing data results and interacting with computers; and
- new methods for storing and accessing information horn very large data archives.

An important characteristic of this system is that different parts of it will be funded and operated by different entities and made available to users in different ways. For example, databases could be operated by government agencies, professional societies, non-profit journals, or commercial firms. Computer facilities could similarly be operated by government, industry, or universities. The network, itself, already is an assemblage of pieces funded or operated by various agencies in the Federal Govemment; by States and regional authorities; and by local agencies, firms and educational institutions. Keeping these components interconnected technologically and allowing users to move smoothly among the resources they need will present difficult management and policy problems.

Furthermore, the system will require significant capital investment to build and maintain, as well as specialized technical expertise to manage. How the various components are to be funded, how costs are to be allocated, and how the key components such as the network will be managed over the long term will be important questions.

Since this system as envisioned would be so widespread and fundamental to the process of research, access to it would be crucial to participation in science. Questions of access and participation are crucial to planning, management, and policymaking for the network and for many of the services attached to it.

Changes in information law brought about by the electronic revolution will create problems and conflicts for the scientific community and may influence how and by whom these technologies are used. The resolution of broader information issues such as security and privacy, intellectual property protection, access controls on sensitive information, and government dissemination practices could affect whether and how information technologies will be used by researchers and who may use them.

Finally, to the extent that, over the long run, modem information technology becomes so fundamental to the research process, it will transform the very nature of that process and the institutions—libraries, laboratories, universities, and so on—that serve it. These basic changes in science would affect government both in the operation of its own laboratories and in its broader relationship as a supporter and consumer of research. Conflicts may also arise to the extent that government becomes centrally involved, both through funding and through management with the traditionally independent and uncontrolled communication channels of science.

NATIONAL IMPORTANCE— THE NEED FOR ACTION

Over the last 5 years, Congress has become increasingly concerned about information technology and research. The National Science Foundation (NSF) has been authorized to establish supercomputer centers and a science network. Bills (S 1067 HR 3131) are being considered in the Congress to authorize a major effort to plan and develop a national research and education network and to stimulate information technology use in science and education. Interest in the role information technology could play in research and education has stemmed, first, from the government's major role as a funder, user, and participant in research and, secondly, from concern for ensuring the strength and competitiveness of the U.S. economy.

Observation 1: The Federal Government needs to establish its commitment to the advanced information technology infrastructure necessary for furthering U.S. science and education. This need sterns directly from the importance of science and technology to economic growth, the importance of information technology to research and development, and the critical timing for certain policy decisions.

Economic Importance

A strong national effort in science and technology is critical to the long-term economic competitiveness, national security, and social well-being of the United States. That, in the modem international economy, technological innovation is concomitant with social and economic growth is a basic assumption held in most political and economic systems in the world these days; and we will take it here as a basic premise. It has been a basic finding in many OTA studies.[1] (This observation is not to suggest that technology is a panacea for all social problems, nor that serious policy problems are not often raised by its use.) Benefits from of this infrastructure are expected to flow into the economy in three ways:

First, the information technology industry can benefit directly. Scientific use has always been a

[1] For example, U.S. Congress, Office of Technology Assessment, *Technology and the American Economic Transition*, OTA-TET-283 (Washington, DC: U.S. Government Printing Office, May 1988) and *Information Technology R&D Critical Trends and Issues*, OTA-CIT-268 (Washington, DC: U.S. Government Printing Office, February 1985),

major source of innovation in computers and communications technology. Packet-switched data communication, now a widely used commercial offering, was first developed by the Defense Advanced Research Projects Agency (DARPA) to support its research community. Department of Energy (DOE) national laboratories have, for many years, made contributions to supercomputer hardware and software. New initiatives to develop higher speed computers and a national science network could similarly feed new concepts back to the computer and communications industry as well as to providers of information services.

Secondly, by improving the tools and methodologies for R&D, the infrastructure will impact the research process in many critical high technology industries, such as pharmaceuticals, airframes, chemicals, consumer electronics, and many others. Innovation and, hence, international competitiveness in these key R&D-intensive sectors can be improved.

The economy as a whole stands to benefit from increased technological capabilities of information systems and improved understanding of how to use them. A National Research and Education Network could be the precursor to a much broader high capacity network serving the United States, and many research applications developed for high performance computers result in techniques much more broadly applicable to commercial firms.

Scientific Importance

Research and development is, inherently, an information activity. Researchers generate, organize, and interpret information, build models, communicate, and archive results, Not surprisingly, then, they are now dependent on information technology to assist them in these tasks. Many major studies by many scientific and policy organizations over the years-as far back as the President's Science Advisory Committee (PSAC) in the middle 1960s, and as recently as a report by COSEPUP of the National Research Council published in 1988[2]—have noted these trends and analyzed the implications for science support. The key points are as follows:

- Scientific and technical information is increasingly being generated, stored and distributed in electronic form;
- Computer-based communications and data handling are becoming essential for accessing, manipulating, analyzing, and communicating data and research results; and,
- In many computationally intensive R&D areas, from climate research to groundwater modeling to airframe design, major advances will depend upon pushing the state of the art in high performance computing, very large databases, visualization, and other related information technologies. Some of these applications have been labeled "Grand Challenges." These projects hold promise of great social benefit, such as designing new vaccines and drugs, understanding global warming, or modeling the world economy. However, for that promise to be realized in those fields, researchers require major advances in available computational power.
- Many proposed and ongoing "big science" projects, from particle accelerators and large array radio telescopes to the NASA EOS satellite project, will create vast streams of new data that must be captured, analyzed, archived, and made available to the research community. These new demands could well overtax the capability of currently available resources.

Timing

Government decisions being made now and in the near future will shape the long-term utility and effectiveness of the information technology infrastructure for science. For example:

- NSF is renewing its multi-year commitments to all or most of the existing National Supercomputing Centers.
- Executive agencies, under the informal auspices of the Federal Research Internet Coordinating Committee (FRICC), are developing a national "backbone" network for science. Decisions made now will have long term influence on the nature of the network, its technical characteristics, its cost, its management, serv-

[2]Panel on Information Technology and the Conduct of Research, Committee on Science, Engineering, and Public Policy, *Information Technology and the Conduct of Research " The User's* View (Washington, DC: National Academy Press, 1989).

ices available on it, access, and the information policies that will govern its use.

- The basic communications industry is in flux, as are the policies and rules by which government regulates it.
- Congress and the Executive Branch are currently considering, and in some cases have started, several new major scientific projects, including a space station, the Earth Orbiting System, the Hubble space telescope, the superconducting supercollider, human genome mapping, and so on. Technologies and policies are needed to deal with these "firehoses of data. " In addition, upgrading the information infrastructure could open these projects and data streams to broad access by the research community.

Observation 2: Federal policy in this area needs to be more broadly based than has been traditional with Federal science efforts. Plsnning, building, and managing the information technology infrastructure requires cutting across agency programs and the discipline and mission-oriented approach of science support. In addition, many parties outside the research establishment will have important roles to play and stakes in the outcome of the effort.

The key information technologies-high performance computing centers, data communication networks, large data archives, along with a wide range of supporting software-are used in all research disciplines and support several different agency missions. In many cases, economies of scale and scope dictate that some of these technologies (e.g., supercomputers) be treated as common resources. Some, such as communication networks, are most efficiently used if shared or interconnected in some way.

There are additional scientific reasons to treat information resources as a broadly used infrastructure: fostering communication among scientists between disciplines, sharing resources and techniques, and expanding access to databases and software, for instance. However, there are very few models from the history of Federal science support for creating and maintaining infrastructure-like resources for science and technology across agency and disciplinary boundaries. Furthermore, since the networks, computer systems, databases, and so on interconnect and users must move smoothly among them, the system requires a high degree of coordination rather than being treated as simply a conglomeration of independent facilities.

However, if information technology resources for science are treated as infrastructure, a major policy issue is one of boundaries. Who is it to serve; who are its beneficiaries? Who should participate in designing it, building and operating it, providing services over it, and using it? The answers to these questions will also indicate to Congress who should be part of the policymaking and planning process; they will govern the long term scale, scope, and the technological characteristics of the infrastructure itself; and they will affect the patterns of support for the facilities. Potentially interested parties include the following:

Users

Potential users might include academic and industrial researchers, teachers, graduate, undergraduate, and high school students, as well as others such as the press or public interest groups who need access to and make use of scientific information. Institutions, such as universities and colleges, libraries, and schools also have user interests. Furthermore, foreign scientists working as part of international research teams or in firms that operate internationally will wish access to the U.S. system, which, in turn, will need to be connected with other nation's research infrastructures.

Collaborators

Another group of interested parties include State and local governments and parts of the information industry. We have identified them with the term "collaborators" because they will be participating in funding, building, and operating the infrastructure. States are establishing State supercomputer centers and supporting local and regional networking, some computer companies participate in the NSF National Supercomputer Centers, and some telecommunication firms are involved in parts of the science network.

Service *Providers*

Finally, to the extent that the infrastructure serves as a basic tool for most of the research and development community, information service providers will require access to make their products available to scientific users. The service providers may include government agencies (which provide access to government scientific databases, for example), libraries and library utilities, journal and text-book publishers, professional societies, and private software and database providers.

*Observation 3: Several information policy issues will be raised in managing and using the network. Depending on how they are resolved, they could sharply restrict the utility and scope of network **use** in the scientific community.*

Security and privacy have already become of major concern and will pose a problem. In general, users will want the network and the services on it to be as open as possible; however, they will also want the networks and services to be as robust and dependable as possible-free free deliberate or accidental disruption. Furthermore, different resources will require different levels of security. Some bulletin boards and electronic mail services may want to be as open and public as possible; others may require a high level of privacy. Some databases may be unique and vital resources that will need a very high level of protection, others may not be so critical. Maintaining an open, easily accessible network while protecting privacy and valuable resources will require careful balancing of legal and technological controls.

Intellectual property protection in an electronic environment may pose difficult problems, Providers will be concerned that electronic databases, software, and even electronic formats of printed journals and other writings will not be adequately protected. In some cases, the product, itself, may not be well protected under existing law. In other cases electronic formats coupled with a communications network erode the ability to control restrictions on copying and disseminating.

Access controls may be called for on material that is deemed to be sensitive (although unclassified) for reasons of national security or economic competitiveness. Yet, the networks will be accessible worldwide and the ability to identify and control users may be limited.

The above observations have been broad, looking at the overall collection of information technology resources for science as an integrated system and at the questions raised by it. The remaining portion of this paper will deal specifically with high performance computers and networking.