PRESIDENT'S INFORMATION TECHNOLOGY ADVISORY COMMITTEE
REPORT TO THE PRESIDENT

Information Technology Research: Investing in Our Future

February 1999

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February 24, 1993

The President
The White House
Washington, D.C.

Dear Mr. President:

On behalf of the National Science Board, I am pleased to present our final report, "Info
Future," on future directions for Federal support o

ACKNOWLEDGEMENTS

Executive Summary

Information Technology will be one of the key factors driving progress in the 21st century—it will transform the way we live, learn, work, and play. Advances in computing and communications technology will create a new infrastructure for business, scientific research, and social interaction. This expanding infrastructure will provide us with new tools for communicating throughout the world and for acquiring knowledge and insight from information. Information technology will help us understand how we affect the naastal environment and how best to protect it. It will provide a vehicle for economic growth. Information technology will make the workplace more rewarding, improve the quality of health care, and make government more responsive and accessible to the needs of our citizens.

Vigorous information technology research and development (R&D) is essential for achieving America's 21st century aspirations. The technical advances that led to today's information tools, such as electronic computers and the Internet, began with Federal Government support of research in partnership with industry and universities. These innovations depended on patient investment in fundamental and applied research.

We have had a spectacular return on that Federal research investment. Businesses that produce computers, semiconductors, software, and communications equipment have accounted for a third of the total growth in U.S. economic production since 1992, creating millions of high-paying new jobs. Government-sponsored University research programs have supported graduate education for many of the leaders and innovators in the field. As we approach the 21st century, the opportunities for innovation in information technology are larger than they have ever been—and mhe qimpor-

the long-term IT research endeavor and to revitalize the computing infrastructure at university campuses and other civilian research facilities, which are rapidly falling behind the state of the art.

Priorities for Research

Four areas of the overall research agenda particularly need attention and must be a major part of a strategic initiative in long-term research and development:

Software – The demand for software has grown far faster than our ability to produce it. Furthermore, the Nation needs software that is far more usable, reliable, and powerful than what is being produced today. We have become dangerously dependent on large software systems whose behavior is not well understood and which often fail in unpredicted ways. Therefore, increases in research on software should be given a high priority. Special emphasis should be placed on developing software for managing large amounts of information, for making computers easier to use, for making software easier to create and maintain, and for improving the ways humans interact with computers. Specifically, the Federal program should:

- Fund fundamental research in software development methods and component technologies.
- Support fundamental research in human-computer interfaces and interaction.
- Support fundamental research in capturing, managing, analyzing, and explainih ir6M.
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Management and Implementation of Federal Information Technology Research –Building a Federal IT program suited to the needs of the Nation in the 21st century will require new management strategies, new modes of research support, and new implementation strategies. This new approach is demanded by the reality of Federal budget constraints, the need for more long-term cross-disciplinary team research, and the need to maintain a small, efficient, and coordinated research man-

EXECUTIVE SUMMARY

1. Information Technology:

1. Communicate	• Scaling for growth and reliability a la the telephone system. • Improving human interaction with computers. • Fragility of systems. • Global networking issues. • Finding best use of new communication possibilities, 1-on-1 and in groups.	• One billion users can access the Internet simultaneously, regardless of language and physical limitations.
2. Deal with Information	• Improving data access methods. • Multi-modal human-computer interaction technologies. • Reliability and bandwidth, better audio and video streaming. • Scalable software support. • High-performance computing. • Delivering and protecting critical information. • Policy for electronic dissemination of	• Everyone can access, query, and print any book, magazine, newspaper, video, data item, or reference document, regardless of language, using mouse, touch screen, speech, or eye blink. • Value is added to information through networked and software-enabled tools.
3. Learn	• Scalability and reliability of the .epded to i .eprastructure. • Improving software technologies for development of education d terials and support of their modifications and maintenance. • Determining the best use of computing and communication technology for effective • Learning how to teach citizens best use of	• Regardless of location, age, handicaps, or schedule, anyone can participate in on-line education programs. • Everyone can access educational d terials to discover the best learning style for them. • Customized educational programs exist for everyone, so no one is left beh-62.
4. Conduct Commerce	• Having sufficient privacy and security to ensure consumer confidence. • Reliability of communication networks, computers, and business applications needs to be high.	• Customers can reach any company regardless of location. • Immediate feedback1rg an rates fast adjustment of marketing strategies and .eventories. • Consumers shop at their convenience. • Companoaunching methods •

5. Work	• Developing high-speed networking for all, regardless of location or handicap. • Developing software to allow effective collaboration. • Ensuring privacy and reliability of the information infrastructure. • Determining how employers, employees, and the self-employed can respond to changes.	• Workers have access to jobs regardless of proximity to population centers. • Workers can live where they want, not needing to be near jobs. • Workplace can better accommodate individual needs.
6. Practice Health Care	• Ensuring privacy of information repositories. • Developing robotics and remote visualization • DeNd nebi-dirtiveoin45 Wto,ocawmixmms.	• Doctors use teleconferencing and telesensing to interview and examine patients.

2. Setting Federal Research Priorities: Findings and Recommendations

Government-funded information technology research has produced enormous innovation. The

Office is less than $20 million out of a total office budget of more than $200 million, an inadequate investment in our judgement. DARPA's new leadership plans to reverse these changes, but recent history shows that Government research managers correctly favor their agencies' missions when budgetary pressures grow and they have to choose between long-term research and short-term mission needs.

Most R&D investment restructuring in the early 1990's was essential for industry and the

disciplinary collaboration, intramural research in academia and Federal research institutes, and joint industry-Government-academia experiments or proofs of concept. Projects of longer duration allow exploration of research problems with multiple-year horizons, which may lead to unexpected and significant discoveries.

It is important that Federal investments include a range of complementary funding modes, including classical single principal investigator (PI) research, multiple-PI experimental research, and mul-

Finding: The Nation is underinvesting in fundamental software research.

Technology for building software is only part of the solution, since we also need to know what soft-

- New types of traffic such as voice, audio, video, or other streamed content.
- Availability, bandwidth, efficiency, reliability, security, and survivability.
- Networks with low to high latency characteristics, as well as the ability to manage them.
- New features such as differentiation of service.
- New uses such as information management.
- New applications such as telemedicine.

We can summarize the research challenges simply. How do we design and build systems and software for deployment on an Internet that is many thousands of times larger and more diverse than today's network? How do we test a system that cannot be built today? How do we ty to msuch a s once it is deployed? How do we add new capabilities without degrading or interrupting the s on which so much depends? How do we create a system that
can evolve capabilities that we cannot imagine today? Answering these questions requires new mathematical and statistical theory dealing with new classes of data distributions, modeling, simulation, experimentation, and testbeds.

Recommendation: Support research on middleware that enables large-scale systems.

Middleware for the scalable information infrastructure is the collection of shared software and rules that will improve the software development process, help tyke the infrastructure operate properly and efficiently, and tyke large new software systems possible. It will provide reusable

let applications software developers concentrate on their applications and not on data transmission or computing issues. It will enable the development of applications that communicate with each other. It will also enable the development of middleware that adapts to a changing environment through services that coordinate and supervise the infrastructure itself. Middleware research topics fall into the two broad categories:

Information management

- Tracking and controlling access to information, protecting privacy, and charging for information where appropriate.

Information and services survivability

Our Nation's security, commerce, education, and well-being depend increasingly on our information infrastructure. It is thus critical to ensure the survivability of that infrastructure in the face of malicious attacks or viruses, equipment or software failures, and overload. Survivability means that services will be available when needed and information will be delivered in a timely fashion. Services must oper0 j i4 12 289.706 ;ces wEormation wils wylivered st opebf

We recommend a periodic review of testbed and research infrastructure activities. This will help ensure that funding and usage is consistent with the research missions for which they are designed. The participants in this review should include representatives from the Federal Large Scale Networking Working Group, the Federal agencies that provide these resources, user communities, and the appropriate private sector communities.

Recommended funding levels

Scalable Information Infrastructure is a relatively new and especially fast moving field, making it difficult to estimate its research and testbed needs conu 9.c Smb usew ts researtopiS1 explarttly itThest,rch it

3.3 High-End Computing

Since its creation under the High Performance Computing Act of 1991, the Federal High Performance Computing and Communications (HPCC) Program has contributed greatly to U.S. technological leadership. The Program has created and disseminated technologies to speed the pace of innovation, enhance national security, promote education, and help us understand the global environment. Furthermore, advances in high-performance technology have become an impor-

- Designing new cancer fighting and anti-viral drugs.
- Understanding the causes and sources of air, water and ground pollution, and devising solu-

and signal processing methods. Activities range from invention and prototyping of new concepts, to improving the ability to use leading-edge commercial products.

Finding: New applications of high-end computing are ripe for exploration.

In addition to advancing the long-term research agenda in traditional high-performance computing, the Committee believes that the Nation needs to develop new uses of high-end computing to promote a better understanding of our world and to improve services to all citizens. This expansion of high-end applications will attract computer, software, and application vendors to support a

At the same time, foreign competitors with substantial government subsidies have enlarged their

to manage this need for continual IT facility improvement (for example, of high-end computers,

iteratively with hardware and software technology investigations. The high-end computing

Federal government continue to provide these computing systems to the research community through major, shared-facility centers. To increase long-term, fundamental research across all scientific and engineering disciplines, the first priority should be to increase the computing capacity of the centers that can best serve the entire research community. These are the NSF Partnerships in Advanced Computational Infrastructure (PACI) centers and the specialized centers that support specific disciplines like NSF's National Center for Atmospheric Research.

The first priority for high-end acquisitions should be to bring the performance level of academic computing close to that of mission agencies; DoE's ASCI program is the current benchmark for 53aigh-end acquis T*vcanovernbudgetstificplansnT* for hightthe comphoule to prdttems toNSTCacity

experiencing. As the pace of IT research and integration accelerates, more decisions will be made

merely skilled users, but researchers, creators, and designers of advanced technology. In this fast-moving field, those people must continue to update their knowledge and skills.

Today we fall far short of meeting these needs, and projections for the future are not encouraging. While the information technology sector and demand for skilled personnel are growing rapidly, the pipeline for computer engineering and computer science graduates is not filling fast enough. Beginning with skills that require a BS-level of training, qualified information technology workers igs n extremrely ceare supplgy.Tthelargeastfraectiol ofopen posictionsexistss n those requining gra-e . InitssInuteim Rephort to theP reident(, th Committese r comended.)Tj T* in cresting th numbter ofH-1B visas as ar shor-utemf r

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It is appropriate that industry take the lead in establishing and implementing privacy procedures. Government regulation might be required if industry fails to act properly, or in very sensitive areas like health care and protection of minors.

Policies for the protection of individuals' information privacy on the Internet should be evaluated and established. Industry education programs should be developed that carry the message that protecting consumer privacy on-line will actually be good for business. The government and industry should jointly fund this is 0 s.

The Committee recommends that research in privacy issues be aggressively funded to help address the following questions:

1. What privacy policies would both protect individual privacy in electronic environments and permit the conduct of business on the Internet? For example, common United States practice is to permit users to "opt-out" of information sharing, but our notification procedures are often lacking. The E.U.'s directive requires full disclosure (notice) and informed consent ("opt-in").

Possible areas of research for such centers include (but are not limited to):

- Transformations of social institutions.
- Governance.
- Electronic commerce research.
- Social and economic simulation and modeling.

Recommendation: Create programs to remove the barriers to high bandwidth connectivity posed by geographic location, size, and ethnic history of research, educational institutions, and communities.

Programs to facilitate high bandwidth connectivity, such as the NSF vBNS connectivity grant program, should be continued and expanded to address problems posed by geographical location, size or ethnic history. It is essential that such limiting factors are removed so that all institutions with

with this fast-changing field. Advances in personal computers and Internet access can enable learn-
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that it fosters high-risk, high-payoff long-term research and invests sufficiently in the core of computer and information science and engineering. We also believe that there needs to be significantly more information technology representation on the National Science Board than exists now.

To successfully carry out the program of research proposed in this document, NSF will need to support a portfolio of modes of research that differ from the current mix of mostly single-investigator research grants together with a small number of centers. For example, multi-investigator projects of longer duration (5-7 years of funding) are needed in order to carry out high-impact experimental research agendas, whether or not such grants are available in other parts of the Foundation. Some of these projects will include long-term basic technology research that has an

Recommendation: Establish a senior-level policy and coordination committee to provide strategic planning and management.

The principal goal of coordination is to ensure that the Federal information technology research

would have worked together to rebuild major applications on parallel computing platforms developing many useful computational support technologies. Unfortunately, many of the projects came

The Committee recommends funding several Expeditions, each with a different focus. The focus

Recommendation: Establish a program of Enabling Technology Centers.

The Committee alsb10 commends establishment of centers of excellence in computer science and engineering research applied to particular applications of information and communications tech-

Conclusion

In both the public and private sectors today, U. S. investments in technology R&D have slowed to