

24 Information Technology Research: Investing in Our Future

**President's Information Technology
Advisory Committee**

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 natural 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.

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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 more important. We have an essential national interest in ensuring a continued flow of good new ideas and trained professionals in information technology.

After careful review of the Federal programs this Committee has concluded that Federal support for research in information technology is seriously inadequate. Research programs intended to maintain the flow of new ideas in information technology and to train the next generation of researchers are funding only a small fraction of the research that is needed, turning away large numbers of excellent proposals. Compounding this problem, Federal agency managers are faced with insufficient resources to meet all research needs and have naturally favored research supporting the short-term goals of their missions over long-term high-risk investigations. While this is undoubtedly the correct local decision for each agency, the sum of such decisions threatens the long-term welfare of the nation.

The Nation needs significant new research on computing and communication systems. This research will help sustain the economic boom in information technology, address important societal problems such as education and crisis management, and protect us from catastrophic failures of the complex systems that now underpin our transportation, defense, business, finance, and healthcare infrastructures. If the results are to be available when needed, we must act now to reinvigorate 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. If we do not take these steps, the flow of ideas that have fueled the information revolution over the past decades may slow to a trickle in the next.

To address these problems, the Committee estimated in its Interim report in August 1998 that the Federal government should increase its support for information technology research by a billion dollars per year by FY 2004. Since that time the Committee has sought comments from the community regarding its preliminary findings and recommendations,

and convened several panels to review those recommendations. This effort produced a more detailed model for the costs of the research programs and other activities needed to address the problems identified in our report. As a result of these activities, the Committee has further refined the findings and recommendations presented in its Interim Report, and adjusted its funding recommendation accordingly. The Committee now recommends that the Federal government increase annual funding for information technology R&D over the five-year period from FY2000 to FY2004, as follows:

**Recommending Funding Increases for
Information Technology R&D (\$ in millions)**

Area	FY00	FY01	FY02	FY03	FY04
Software	112	268	376	472	540
Scalable Information					
Infrastructure	60	120	180	240	300
High-End Research	180	205	240	270	300
High-End Acquisitions	90	100	110	120	130
Socioeconomic	30	40	70	90	100
Total	472	733	976	1192	1370

These increases are in addition to the programs in existence in FY99. The full report provides additional details on these budget recommendations, including discussions of the method used to produce them.

Although there are unmet needs across the entire spectrum of research activities, priority for increased funding should be on long-term, high-risk investigations. In addition to increases for research itself, the Federal government must also ensure that the research community is equipped with the state-of-the-art facilities needed to carry out advanced projects. Finally, Federal budgets must continue to ensure that advances in information technology work to benefit all Americans and that all Americans have the education and training needed to prosper in a world that will increasingly depend on information technology.

To be successful, the expanded Federal research program we propose must be effectively managed. Current cross-agency coordination mechanisms are working well, but they suffer from the lack of well-defined responsibilities for ensuring that key areas are not overlooked. There has been no agency with the primary responsibility for ensuring that long-term, high-risk research is protected from the pressures that arise in mission agencies. Ideally there should be an agency charged with leading

the organization of a fundamental information technology research program appropriate for the 21st century.

The Administration's proposed Federal budget for FY 2000 demonstrates a commitment to sustained growth in information technology research through its initiative, *Information Technology for the Twenty-First Century (IT2)*. This commitment is an important first step in what must be a continuing effort on the part of the Federal government to increase research dollars and to create a new management system designed to foster innovative research. But the effort cannot stop here. Further increases and continued oversight are needed to remedy the shortfall in long-term research investments that has accrued.

Findings and Recommendations

Federal information technology R&D investment is inadequate. Measured in constant (non-inflated) dollars, support in most critical areas has been flat or declining for nearly a decade, while the importance of information technology to our economy has increased dramatically. As a result, the Nation is gravely underinvesting in the long-term, high-risk research that can replenish the reservoir of ideas that will lead to innovations in information technology in generations to come.

Federal information technology R&D is too heavily focused on near-term problems. Much of the Federal investment in information technology R&D is being funded by mission agencies. In the face of the enormous increases in information technology problems to be addressed, funding agencies have had to prioritize their investments. Inevitably, priority has been given to short-term, mission-oriented goals over long-term research. This reflects the situation in the private sector as well. As a result, investment in long-term, high-risk research has been curtailed. This trend threatens to interrupt the flow of ideas that has driven the information economy in this decade and threatens efforts to solve nationally important problems.

Recommendation: Create a strategic initiative in long-term information technology R&D. To address these problems the Committee recommends that the President create a strategic initiative to support long-term research in fundamental issues in computing, information, and communications. The initiative should increase the total funding base by \$1.37 billion per year by FY 2004. The Federal funding agencies should use the resulting budget increases to encourage research that is visionary and high-risk. To do this, they will need to diversify modes of

research support and increase the duration of projects. The goal should be to recapture in the universities and research labs much of the excitement that existed at top-rated departments in the past.

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 explaining information and in making it available for its myriad of uses.
- Make software research a substantive component of every major IT research initiative.

Scalable Information Infrastructure

Our Nation's dependence on the Internet is increasing. While this is an exciting development, the Internet is growing well beyond the intent of its original designers and our ability to extend its use has created enormous challenges. As the size, capability, and complexity of the Internet grows, it is imperative that we do the necessary research to learn how to build and use large, complex, highly-reliable, and secure systems. It is therefore important that the Federal government:

- Fund research on understanding the behavior of the global-scale network and its associated information infrastructure. This should include collecting and analyzing performance data and modeling and simulating network behavior.
- Support research on the physics of the network, including optical and wireless technologies including satellites, cable, and bandwidth issues.
- Support research to anticipate and plan for scaling the Internet. Support research on middleware that enables large-scale systems.
- Support research on large-scale applications and the scalable services they require.
- Fund a balanced set of testbeds and research infrastructure that serve the needs of networking research, research in enabling information technologies and advanced applications.

High-End Computing

Extremely fast computing systems, with both rapid calculation and rapid data movement, are essential to provide accurate weather and climate forecasting, to support advanced manufacturing design, to design new pharmaceuticals, to conduct scientific research in a variety of different areas, and to support critical national interests. Although they achieve remarkable performance in some cases, the current scalable, parallel, high-end computing systems are not well suited to many nationally important, strategic applications. To ensure that U.S. scientists continue to have access to computers of the highest possible power, fund-

ing should be focused on innovative architectures, hardware technologies, and software strategies that overcome the limitations of today's systems. Without major increases in funding in these areas, the realizable performance of new machines will fall far short of their potential. We specifically recommend that the Federal program should:

- Fund research into innovative computing technologies and architectures.
- Fund R&D on software for improving the performance of high-end computing.
- Drive high-end computing research by trying to attain a sustained petaops/petaflops on real applications by 2010 through a balance of software and hardware strategies.
- Fund the acquisition of the most powerful high-end computing systems to support science and engineering research.
- Expand the National Science and Technology Council (NSTC) Computing Information and Communications (CIC) High-End Computing and Computation (HECC) Working Group's coordination process to include all major elements of the government's investment in high-end computing.

Socioeconomic Impacts

Information technology will significantly improve the flow of information to all people and institutions in the Nation, and could be a powerful tool for democratization. Our National well-being depends on understanding the potential social and economic benefits of on-going advances in information technology. However, problems are arising from the increasing pace of information technology-based transformations. To realize the promise of the new technologies, we must invest in research to identify, understand, anticipate, and address these problems. We must develop concrete objectives and comprehensive metrics through which to assess the ongoing transformations brought about by the integration

of information technology into our lives. We must conduct careful research on the impact of the transformations against the objectives, and develop appropriate policies to deal with the knowledge we gain from the research. The Federal government should:

- Expand Federal initiatives and government/university/industry partnerships to increase information technology literacy, access and research capabilities.
- Expand Federal research into policy issues arising from information technology.
- Fund information technology research on socioeconomic issues.
- Expand the participation of underrepresented minorities and women in computer and information technology careers.
- Create programs to remove the barriers to high bandwidth connectivity posed by geographic location, size, and ethnic history of research, educational institutions, and communities.
- Accelerate and expand education in information technology at all levels—K-12, higher education, and lifelong learning.
- Strengthen the use of information technology in education.

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 management process. It is essential that the Federal systems responsible for managing and implementing the new IT program be positioned to review the entire information technology research budget, to restore the balance between fundamental and applied research, to encourage long-term and high-risk

collaborative research projects, and to employ a systematic review by participating Federal agencies and the private sector.

To achieve these goals, we recommend that the existing Federal information technology management and implementation structure be enhanced as follows:

- Strongly encourage NSF to assume a leadership role in basic information technology research. Provide NSF the necessary resources to play this role.
- Designate a Senior Policy Official for information technology R&D.
- Extend the HPCC program coordination model to all major Federal information technology R&D activities.
- Diversify the modes of research support to include more projects of broader scope and longer duration, placing a renewed emphasis on research carried out in teams.
- Fund collaborations with applications to drive information technology research, but take measures to ensure that research remains a primary goal.
- Fund centers for Expeditions into the 21st Century.
- Establish a program of Enabling Technology Centers that will drive research by examination of critical applications areas.
- Establish an annual review of research objectives and funding modes.

The Government's Essential Role

While the importance of information technology to the future of the economy and the government is clear, it may not be immediately obvious that government investment is needed to ensure continued progress. The PITAC members from industry were unanimous in their opinion that it is not feasible for the private sector to assume responsibility for long

term, high-risk research, in spite of the success of the information technology industry. Their opinion is found in the attached sidebar.

We believe that the Federal Government must retain and expand its role in leading long-term fundamental research in information technology. Advanced Government services and national security depend on it. The benefits to our Nation and society will be huge. A loss of international leadership in information technology would be economically devastating.

We cannot rely on industry to fund the needed research because they necessarily focus, in view of economic realities, on the short term. Industry cannot and will not invest in solving problems of importance to society as a whole unless such investments make sense from a business perspective.

The rationale for funding long-term information technology research goes far beyond economic benefit and national security needs. Enormous societal gains can be reaped from advances in information technology. Only through research on a scale substantially greater than is being carried out today, can we build an infrastructure that will be available, affordable and usable by all citizens—one that can support the compelling “transformations” discussed in the next chapter of this report.

Federal investment in information technology directly supports the education and preparation of our young people for careers in information technology research, and the training of workers who need to upgrade their skills to keep pace with a changing marketplace. Trained people are not just a byproduct but rather a major product of publicly supported research. These trained professionals are critical national infrastructure, and will create and develop new ideas, form a talent pool for existing business, and launch new companies.

The benefits that the transformations described in the next chapter of this report can have for our Nation's future are extraordinary. A networked society can reach out to all its citizens, and can bring our Nation closer together and address many societal issues. While it cannot resolve all these issues, information technology can give us leverage toward their solution.

But the realization of the positive transformations we will describe in the next chapter of this report is not guaranteed. The realization of each transformation will depend on the results of aggressive, well-managed Federal research programs. Long-term Federal investment in information technology research is necessary to incubate ideas to the point

of clear commercial viability, and to develop methods of measuring and tracking our progress toward realizing our positive vision.

Conclusion

In both the public and private sectors today, U.S. investments in technology R&D have slowed to a relative trickle. American businesses, in an ever-shrinking and more highly competitive world, have devoted less and less of their precious resources to long-term R&D, directing their efforts instead to reducing costs and getting new products into the pipeline today at the expense of the future. The Federal government has mirrored this trend because of dramatically increasing pressures on the research and development budgets, with only modest increases in funding levels. Funding agency managers have responded by making the natural and correct decision to favor the short-term needs of their missions over the need for long-term research in information technology. The U.S. Government's lead in research in high end computing and computation—so crucial to keeping our military edge in the competitive era of the Cold War—seems to have come down along with the Berlin Wall.

As a result, the once robust technological edge the U.S. has enjoyed over the rest of the world is actually built on an increasingly fragile technological substructure. If the trend away from long-term research continues, the flow of bold new ideas that has fueled the information economy in this decade is likely to slow to a trickle by 2010. To keep its competitive edge, the United States must rededicate itself to cutting edge high-tech research and development—or risk being overcome by nations with a clearer plan and a stronger view of the future. This is a risk the Nation cannot afford to take.

The initiatives proposed in this report would represent a major step toward restoring long-term Federal research in information technology to levels that will ensure continued prosperity and new technological solutions to national problems in the next millennium. The time to act is now and the Federal government has a unique role to play in supporting research in this critical area. The Brooks/Sutherland report stated this well:

Very few companies are able to invest for a payoff that is 10 years away. Moreover, many advances are broad in their applicability and complex enough to take several engineering iterations to get right,

and so the key insights become 'public' and a single company cannot recoup the research investment. Public investment in research that creates a reservoir of new ideas and trained people is repaid many times over by jobs and taxes in the information industry, more innovation and productivity in other industries, and improvements in the daily lives of citizens. This investment is essential to maintain U.S. competitiveness.*

This committee strongly recommends that the Federal government embark upon the kind of leading-edge, visionary research necessary to continue the revolution that has transformed the lives of our citizens in ways not thought possible just thirty years ago. The recommendations of this committee also stress the needs to: 1) to upgrade the knowledge base and skills of our workforce, so that our citizens will be prepared to face a new century fully prepared for the technological challenges that are yet to come; and 2) to give all American the opportunity to participate in the information age, so that our citizens will be able to fulfill its promise. These steps, if taken now, will bring handsome returns to the Nation over the coming decades.

*Brooks, Jr., Frederick P., and Sutherland, Ivan E., co-chairs. *Evolving the High Performance Computing and Communications Initiative to Support the Nation's Information Infrastructure*. Prepared by Committee to Study High Performance Computing and Communications: Status of a Major Initiative. Washington, DC: National Academy Press, 1995.