Designing a Digital Future

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"Designing a Digital Future" is the title of a December 2010 report to the President of the United States from the President's Council of Advisors on Science and Technology (PCAST) – a periodic Congressionally-mandated review of the Federal Networking and Information Technology Research and Development (NITRD) Program.[1]

Why should the Federal government invest in computing research? Computer science, despite its name, is predominantly an engineering field. Although some view "research" as a property only of the traditional physical and biological sciences – equating engineering fields with industrial technology development – the PCAST NITRD report gives a compelling argument for the importance of fundamental computing research and for the role of the Federal Government. That argument is summarized in the excerpts from the report that appear in italics below.

Networking and information technology R&D changes the world

From smartphones to eBook readers to game consoles to personal computers; from corporate datacenters to cloud services to scientific supercomputers; from digital photography and photo editing, to MP3 music players, to streaming media, to GPS navigation; from robot vacuum cleaners in the home, to adaptive cruise control in cars and the real-time control systems in hybrid vehicles, to robot vehicles on and above the battlefield; from the Internet and the World Wide Web to email, search engines, eCommerce, and social networks; from medical imaging, to computer-assisted surgery, to the large-scale data analysis that is enabling evidence-based healthcare and the new biology; from spreadsheets and word processing to revolutions in inventory control, supply chain, and logistics; from the automatic bar-coding of hand-addressed first class mail, to remarkably effective natural language translation, to rapidly improving speech recognition – our world today relies to an astonishing degree on systems, tools, and services that belong to a vast and still growing domain known as Networking and Information Technology (NIT).

Networking and information technology R&D drives our prosperity

Unless the Nation's economy continues to thrive, none of our goals in energy, healthcare, education, national security or other crucial areas will be achievable – and the expansion and advancement of NIT are key drivers of America's economic competitiveness.

[1] Complete materials related to the PCAST NITRD report may be found at http://cra.org/nitrd/ or on the PCAST website http://www.whitehouse.gov/administration/eop/ostp/pcast/.

The enormous economic impact of NIT derives not only from the growth of the NIT industry itself, but to an even greater extent from NIT-enabled productivity gains across the entire economy. The development and application of NIT-related systems, services, tools and methodologies have boosted U.S. labor productivity more than any other set of forces in recent decades. Advances in NIT, deployed pervasively throughout the U.S. economy, have helped U.S. workers become the world's most productive and have enabled the U.S. to remain one of the world's most competitive economies. …

While the fruits of NIT advances are most evident in the rise of the modern technology sector – now-familiar corporate names such as Apple, Facebook, Google, Intel, Microsoft, and others – the impact in other areas of the economy has been equally dramatic. Companies as diverse as FedEx and Walmart, although they provide services that existed long before the current technology boom, have used advances in NIT to revolutionize their industries, boosting operational efficiency and economic output to an unprecedented extent. Small and mid-size companies have also gained new capabilities and efficiencies through the use of NIT. Whether it is access to powerful yet affordable systems that allow virtual prototyping for parts suppliers, point-of-sale systems that allow for precise inventory controls, or simply the availability of sites like Etsy.com that make it easy for communities of artists to reach customers, advances in NIT empower U.S. businesses, augment their competencies, and enable them to compete successfully in an increasingly global economy.

Networking and information technology is the dominant factor in America's science and technology employment

All indicators – all historical data, and all projections – argue that NIT is the dominant factor in America's science and technology employment, and that the gap between the demand for NIT talent and the supply of that talent is and will remain large. Increasing the number of graduates in NIT fields at all degree levels must be a national priority.

The Federal Government has played, and must continue to play, an essential role

The Federal Government has played an essential role in fostering the advances in NIT that have transformed our world. Steady Federal investment in NIT research over the past 60 years has led to many of the breakthroughs noted above, often a decade or more after the research took place. The Federal investment in NIT research and development is without question one of the best investments our Nation has ever made. …

Of course, the Government is not alone in investing in NIT R&D. Industry has made, and continues to make, major contributions. It is important, however, not to equate the very large industry R&D investment in NIT with fundamental research of the kind that is carried out in universities and a small number of industrial research labs. The vast majority of industry R&D in NIT is focused on development – on the engineering of future products and product versions. Few major NIT companies have formal research organizations, and even those that do invest relatively little in research compared to their

investment in development activities. Fundamental research with the potential for future transformational application represents a small fraction of overall industry R&D in NIT – a situation that is both appropriate and unlikely to change. For that reason, among others, Federal investment in NIT R&D is and will remain essential.

There is tremendous potential for – and tremendous need for – further breakthroughs

As a field of inquiry, NIT has a rich intellectual agenda – as rich as that of any other field of science or engineering. In addition, NIT is arguably unique among all fields of science and engineering in the breadth of its impact. …

Recent technological and societal trends place the further advancement and application of NIT squarely at the center of our Nation's ability to achieve essentially all of our priorities and to address essentially all of our challenges:

- *Advances in NIT are a key driver of economic competitiveness …*
- *Advances in NIT are crucial to achieving our major national and global priorities in energy and transportation, education and life-long learning, healthcare, and national and homeland security …*
- *Advances in NIT accelerate the pace of discovery in nearly all other fields …*
- *Advances in NIT are essential to achieving the goals of open government.*

Many areas of networking and information technology are now as important as high performance computing as measures of our nation's competitiveness

Effective use of NIT in increasing our economic competitiveness and achieving our other national priorities depends not only on incorporating innovative NIT into a wide variety of domains, but also on ensuring that the basic science and engineering of NIT remain vibrant and strong. At the time of the High-Performance Computing Act of 1991, the importance of high performance computing and communication (HPCC) to scientific discovery and national security was a major factor underlying the special attention given by Congress to NIT. Although HPCC continues to contribute in important ways to scientific discovery and national security, many other aspects of NIT have now risen to comparable levels of importance. Among these NIT areas are the interactions of people with computing systems and devices, both individually and collectively; the interactions between NIT and the physical world, such as in sensors, imaging, robotic and vision systems, and wearable and mobile devices; large-scale data capture, management and analysis; systems that protect personal privacy and sensitive confidential information, are robust in the face of malfunction, and stand up to cyber-attack; scalable systems and networking (i.e., systems and networks that can be either increased or decreased in complexity, size, generality, and cost); and software creation and evolution. HPCC is but one of many important areas of NIT, and America's prowess in HPCC is but one of many measures of our international competitiveness in NIT.

Within high performance computing, competition based on traditional benchmarks should not be allowed to crowd out game-changing research or efforts to extract maximum benefit from leading-edge systems

In today's environment … the notion of "high performance" must assume a broader meaning, encompassing not only the traditional metric of floating-point operations per second (FLOPS), but also the ability to efficiently manipulate vast and rapidly increasing quantities of both numerical and non-numerical data, to handle problems requiring real-time response, and to accelerate many applications that were either non-existent or far less important at the time of NITRD's creation under the High Performance Computing Act of 1991.

Competition within the international community to develop what are typically described as the world's most powerful supercomputers has been based to a large extent on a single metric that, while relevant to certain HPC applications, increasingly fails to reflect the broad range of capabilities our Nation needs in the area of high performance computing. …

While it would be imprudent to allow ourselves to fall significantly behind our peers with respect to scientific performance benchmarks that have demonstrable practical significance, a single-minded focus on maintaining clear superiority in terms of FLOPS count is probably not in our national interest. Engaging in such an "arms race" could be very costly, and could divert resources away from basic research aimed at developing the fundamentally new approaches to HPC that could ultimately allow us to "leapfrog" other nations, maintaining the position of unrivaled leadership that America has historically enjoyed in high performance computing.

The Nation is investing far less in networking and information technology R&D than is shown in the Federal budget

The Nation is actually investing far less in NIT R&D than is shown in the Federal budget. A substantial fraction of the NITRD crosscut budget represents spending on NIT that supports R&D in other fields, rather than spending on R&D in the field of NIT itself. …

For some NITRD agencies, such as the National Science Foundation, the amount included in the NITRD crosscut is a reasonably accurate representation of the agency's investment in NIT R&D. For other agencies, there can be significant discrepancies. These discrepancies arise, for the most part, due to confusion between true NIT R&D and NIT that supports R&D in other fields. The latter is legitimately part of an agency's R&D portfolio – often a crucially important part. But it is not NIT R&D. …

By leading policymakers to believe that we are spending much more on such activities than is actually the case, this discrepancy contributes to a substantial, systematic underinvestment in an area that is critical to our national and economic security.

There must be specific new investments in networking and information technology R&D focused on achieving America's priorities

The Federal Government must invest in new multi-agency NIT R&D initiatives in areas of particular importance to our national priorities. … We see three areas in which such initiatives are particularly timely and important.

- *A national, long-term, multi-agency research initiative on NIT for health that goes well beyond the current national program to adopt electronic health records. …*
- *A national, long-term, multi-agency, multi-faceted research initiative on NIT for energy and transportation. …*
- *A national, long-term, multi-agency research initiative on NIT that assures both the security and the robustness of cyber-infrastructure.*

There must be increased investment in networking and information technology research frontiers that will accelerate progress across a broad range of priorities

Among such investments:

- *A broad, multi-agency research program on the fundamentals of privacy protection and protected disclosure of confidential data. …*
- *A collaborative research program that augments the study of individual human-computer interaction with a comprehensive investigation to understand and advance human-machine and social collaboration and problem-solving in a networked, on-line environment …*
- *Fundamental research in data collection, storage, management, and automated large-scale analysis based on modeling and machine learning. …*
- *Research in advanced domain-specific sensors, integration of NIT into physical systems, and innovative robotics in order to enhance NIT-enabled interaction with the physical world.*

A broad, high-level standing committee dedicated to providing sustained strategic advice in networking and information technology should be established

A successful coordinated attack on the Nation's most challenging and important problems requires focused attention on multi-disciplinary, problem-driven research in NIT. That focus must come from Federal leadership. … That leadership must have continuity, breadth and depth, and a focus on NIT. …

The Federal Government must lead in ensuring that strong multi-agency R&D investments are made in NIT to address important national priorities:

- *The White House Office of Science and Technology Policy should establish a broad, high-level standing committee of academic scientists, engineers, and industry leaders dedicated to providing sustained strategic advice in NIT.*
- *The National Science and Technology Council should lead in defining and promoting the major NIT research initiatives that are required to achieve the most important existing and emerging national priorities.*

Science, Technology, Engineering, and Mathematics (STEM) education must be improved, and computer science must be embraced as an essential component of STEM

The National Science and Technology Council's Committee on STEM Education … must exercise strong leadership to bring about fundamental changes in K-12 STEM education in the United States, among them the incorporation of computer science as an essential component. …

Fluency with NIT skills, concepts, and capabilities; facility in computational thinking; and an understanding of the basic concepts of computer science must be an essential part of K-12 STEM education.

More accurate reporting of our nation's networking and information technology R&D investment is essential

It is important that investments in NIT that support R&D in other fields be clearly differentiated from investments in NIT R&D. … The National Coordination Office for NIT R&D and the White House Office of Management and Budget should redefine the budget reporting categories to separate NIT infrastructure for R&D in other fields from NIT R&D, and should ensure more accurate reporting of both NIT infrastructure investment and NIT R&D investment.

In summary

Computing research – networking and information technology R&D – changes our world, drives our prosperity, and enables advances in all other fields.

The Federal Government has played an essential role in fostering these breathtaking advances. The Federal investment in computing research is without question one of the best investments our Nation has ever made.[2]

The future is bright. There is tremendous opportunity – and tremendous need – for further breakthroughs. The Federal Government's essential role in fostering these advances – in supporting fundamental research in computing and other engineering fields – must continue.

Today, the Nation is investing far less in networking and information technology R&D than is shown in the Federal budget. There must be specific new investments in computing research focused on achieving America's priorities in areas such as health care, energy, transportation, national and homeland security, discovery in science and engineering, education, and digital democracy. And there must be specific new investments in computing research frontiers that will accelerate progress across a broad range of priorities – investments that will yield fundamental advances in areas such as the interactions of people with computing systems and devices, both individually and collectively; the interactions between computing systems and the physical world, such as

[2] National Academies Press. (2003). *Innovation in Information Technology.*

in sensors, imaging, robotic and vision systems, and wearable and mobile devices; large-scale data capture, management and analysis; systems that protect personal privacy and sensitive confidential information, are robust in the face of malfunction, and stand up to cyber-attack; scalable systems and networking (i.e., systems and networks that can be either increased or decreased in complexity, size, generality, and cost); software creation and evolution; and fundamentally new approaches to high performance computing that could ultimately allow us to "leapfrog" other nations.

We must design our digital future; it will not just happen. There is no field of science or engineering in which the continuation – or the loss – of America's position of global leadership will be of greater consequence.

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