Information Technology R&D and U.S. Innovation

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Advances in information technology are transforming all aspects of our lives: commerce, education, employment, health care, manufacturing, government, national security, communications, entertainment, science, and engineering.

Advances in information technology also drive our economy – both directly (the IT sector itself) and indirectly (all other sectors that are "powered" by advances in IT). Recent analysis suggests that the remarkable economic growth the U.S. experienced between 1995 and 2002 was spurred by an increase in productivity enabled almost completely by factors related to IT[2]. The processes by which advances in information technology enable productivity growth, enable the economy to run at full capacity, enable goods and services to be allocated more efficiently, and enable the production of higher quality goods and services are now well understood[3].

Advances in information technology enable innovation in all other fields. In business, advances in IT are giving researchers powerful new tools, enabling small firms to significantly expand R&D, boosting innovation by giving users more of a role, and letting organizations better manage the existing knowledge of its employees[2, pp. 46-48]. In science and engineering, advances in IT are enabling discovery across every discipline – from mapping the human brain to modeling climatic change. Researchers, faced with research problems that are ever more complex and interdisciplinary in nature, are using IT to collaborate across the globe, and to collect, manage, and explore massive amounts of data.

Advances in information technology continue unabated. Worldwide, there has been no slowdown in the pace of innovation, the production of new ideas, the discovery of additional opportunities to advance products and services for society.

Thus, leadership in information technology is essential to the nation, economically and socially.

The future is full of opportunity. Several months ago, the National Academy of Engineering unveiled 14 "Grand Challenges for Engineering" for the 21st century (http://www.engineeringchallenges.org/). The majority of these – the majority of the "Grand

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[1] For the most current version of this essay, as well as related essays, visit http://www.cra.org/ccc/initiatives
[2] Jorgenson, Dale W., Mus S. Ho, and Kevin J. Stiroh. *Productivity, Volume 3: Information Technology and the American Growth Resurgence*. MIT Press. 2005.
[3] Atkinson, Robert D., Andrew S. McKay. *Digital Prosperity: Understanding the Economic Benefits of the Information Technology Revolution*. Information Technology and Innovation Foundation. 2007. http://www.itif.org/files/digital_prosperity.pdf

Challenges" for *all* of engineering – have either substantial or predominant information technology content:

- Secure cyberspace
- Enhance virtual reality
- Advance health information systems
- Advance personalized learning
- Engineer better medicines
- Engineer the tools of scientific discovery
- Reverse-engineer the brain
- Prevent nuclear terror (to a great extent a sensor network and data mining problem)

And there are many more information technology challenges of equally high impact:

- Create the future of networking
- Empower the developing world through appropriate information and communication technology
- Revolutionize transportation safety and efficiency
- Build truly scalable computing systems, and devise algorithms for extracting knowledge from massive volumes of data
- Engineer advanced "robotic prosthetics" and, more broadly, enhance people's quality of life
- Instrument your body as thoroughly as your automobile
- Engineer biology (synthetic biology)
- Revolutionize our electrical energy infrastructure: generation, storage, transmission, and consumption
- Achieve quantum computing

It is impossible to imagine a field with greater opportunity to change the world.

Federally sponsored research provides the foundation for progress. Key to the role that IT plays in enabling innovation is the role of the IT R&D ecosystem that enables innovation within IT. At the heart of this IT R&D ecosystem is federally sponsored research. A 1995 study by the National Research Council[4] describes the "extraordinarily productive interplay of federally funded university research, federally and privately funded industrial research, and entrepreneurial companies founded and staffed by people who moved back and forth between universities and industry." That study, and a subsequent 1999 report by the President's Information Technology Advisory Committee[5], emphasized the "spectacular" return on the federal investment in long-term IT research and development. Indeed, a 2003 NRC study[6] identified 19 multibillion-dollar IT industries – industries that are transforming our lives and driving our economy – that were enabled by federally sponsored research. (See http://books.nap.edu/openbook.php?record_id=10795&page=5.)

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[4] National Research Council. *Evolving the High Performance Computing and Communications Initiative to Support the Nation's Information Infrastructure.* National Academies Press. 1995. http://www.nap.edu/catalog.php?record_id=4948

[5] President's Information Technology Advisory Committee. *Information Technology Research: Investing in Our Future.* 1999. http://www.nitrd.gov/pitac/report/pitac_report.pdf

[6] National Research Council. *Innovation in Information Technology.* National Academies Press. 2003. http://www.nap.edu/catalog.php?record_id=10795

The two dominant federal agencies in IT innovation have been the National Science Foundation (NSF) and the Defense Advanced Research Projects Agency (DARPA). The Networking and Information Technology Research and Development (NITRD) program, which coordinates the U.S. federal government's investments in IT R&D, includes 13 federal agencies (http://www.nitrd.gov/subcommittee/agency-web-sites.htm). Most NITRD agencies – for example, the National Oceanic and Atmospheric Administration (NOAA), the National Aeronautics and Space Administration (NASA), the Department of Energy (DOE), and the National Institutes of Health (NIH) – tend to invest in applications geared to their respective missions, leaving the support of broad-based innovation to NSF and DARPA. In general, a worrisome bias in the federal IT R&D portfolio towards short-term, application-oriented R&D has been noted, most recently in a 2007 review of the NITRD program by PCAST[7].

Policy changes at DARPA have left NSF standing largely alone, jeopardizing a key element of the IT R&D ecosystem. Changes such as wider classification of programs, increased restrictions on the participation of foreign nationals, frequent "go/no-go" program reviews, and a general foreshortening of the research horizon have caused a significant reduction in university participation in DARPA programs in all fields, but have affected IT disproportionately because of the traditional role that DARPA has played in the field. Today, NSF provides 86% of the federal support for academic research in computer science[8], a far greater proportion than for any other field. (For example, NSF provides 40% of the support for the physical sciences, and 46% of the support for engineering.) To a significant extent, increases in NSF funding for IT research at the start of this decade merely offset decreased DARPA academic engagement, which diminished the transformative effect that had been anticipated.

NITRD coordination has had limited effectiveness. This is starkly evident in the case of cybersecurity, as pointed out in a 2005 report from the President's Information Technology Advisory Committee[9]. The classification of DARPA cybersecurity programs left a significant gap in what PITAC referred to as "fundamental research on civilian cybersecurity." To first approximation, only NSF stepped up, and at a very modest level relative to the threats that the nation faces.

Failure to act will jeopardize U.S. leadership in IT, and constrain the pace of U.S. innovation across the economy, imperiling many of the gains those innovations have enabled. PCAST's 2007 review of the NITRD program noted that the most critical need is to "rebalance the NITRD investment portfolio to include more long-term, large-scale, multidisciplinary IT R&D." The review also found that changes are needed in IT education efforts, training the IT workforce, technical areas in which the NITRD program invests, the rate of technology transfer, and NITRD's own planning and assessment processes.

One critical action is to launch a second Information Technology Research program in the NSF CISE Directorate. Between FY2000 and FY2004, the original ITR program added $218

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[7] President's Council of Advisors on Science and Technology. *Leadership Under Challenge: Information Technology R&D in a Competitive World*. 2007. http://www.ostp.gov/pdf/nitrd_review.pdf

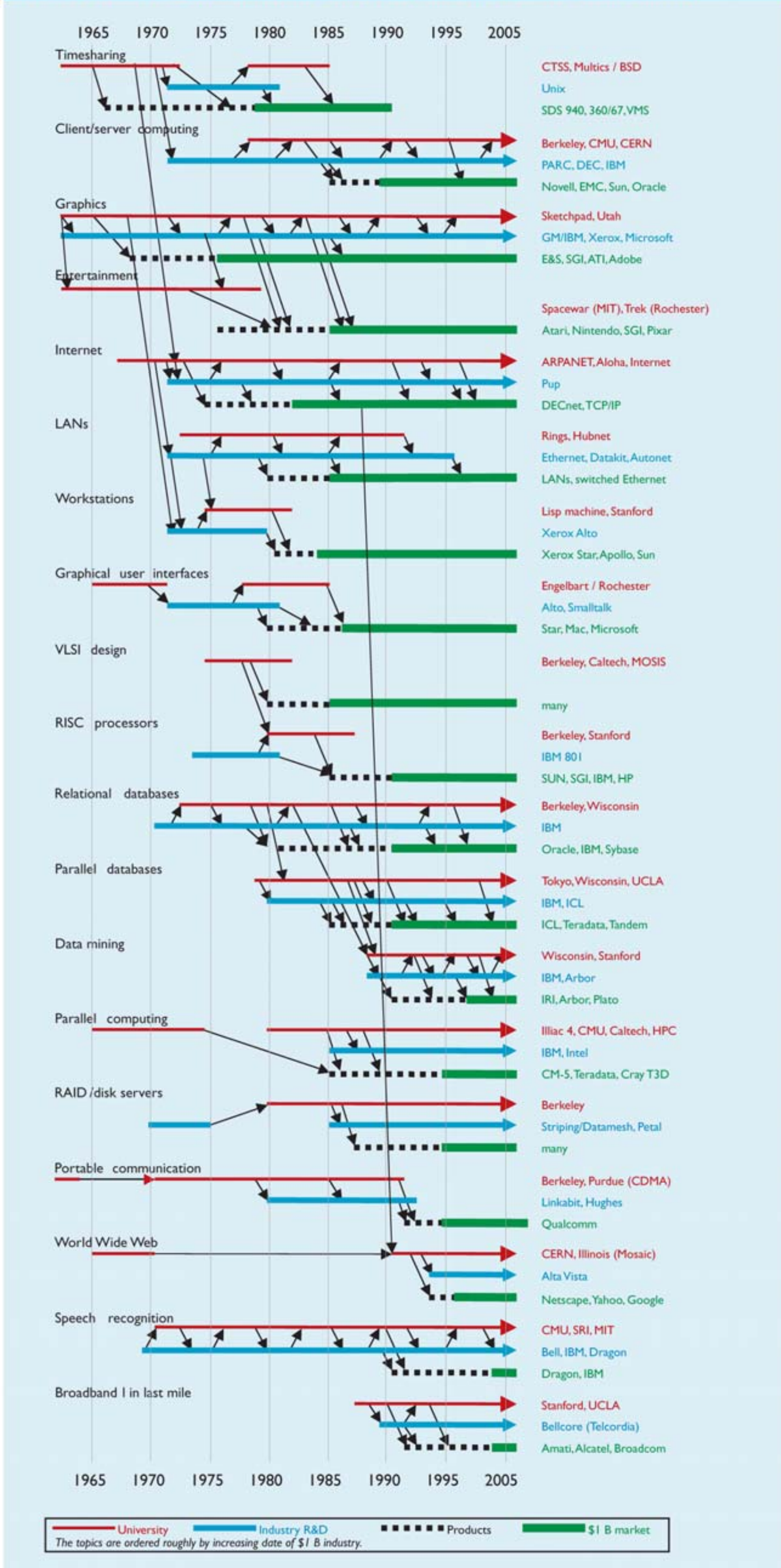
[8] National Science Foundation. *FY 2008 Budget Request to Congress.* 2007. http://www.nsf.gov/about/budget/fy2008/pdf/EntirePDF.pdf

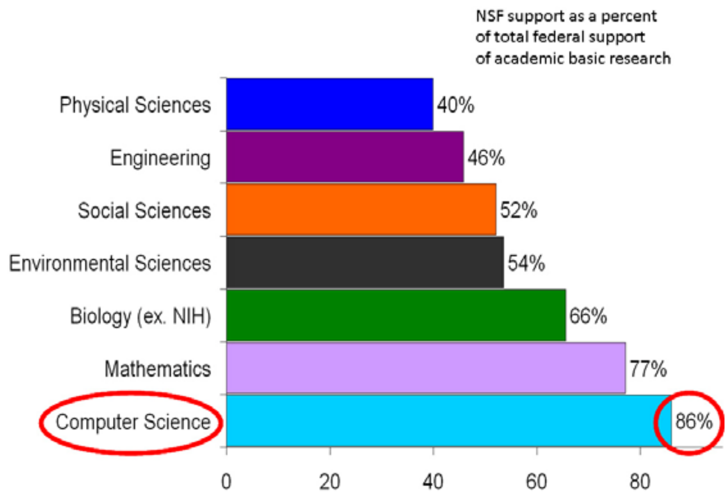
[9] President's Information Technology Advisory Committee. Cyber Security R&D: A Crisis of Prioritization. 2005. http://www.nitrd.gov/pitac/reports/20050301_cybersecurity/cybersecurity.pdf

million to what is today (FY2008) an NSF CISE budget of $535 million – which constitutes 86% of the federal support for academic research in computer science. (ITR also added $77 million to other Directorate's budgets.) ITR was managed as a distinct program, and had a particularly important impact in encouraging *longer-term*, *larger-scale*, *multidisciplinary* IT R&D focused on *areas of particular opportunity*. The impact would have been even greater had not DARPA's academic engagement decreased – another issue that must be tackled.

Today's research is tomorrow's infrastructure. When our nation faces immediate challenges, the feasible solutions depend upon the ideas, resources, and designs that are "on the shelf," ready to deploy. Whether the challenge is restoring New Orleans, defeating improvised explosive devices, thwarting cybercrime and cyberterrorism, transforming the safety and efficiency of our transportation system, building a 21^{st} century electrical energy infrastructure, or revolutionizing our health care system, we can't get anything done quickly if we haven't already explored the solution space, tested the ideas, run the pilot projects, and had experience with "solutions at scale." Without this preparation, we can spend vast amounts of money unwisely, and fail to achieve the results we need. So an important ingredient in infrastructure investment is to invest in the ideas, resources, and designs for *tomorrow's infrastructure*. Without a vigorous program of renewal of the infrastructure basics, we build the wrong thing, and the infrastructure degrades, sometimes rapidly. A wise program of infrastructure investment will *build today's infrastructure* and *design tomorrow's infrastructure*. Increasingly, information technology is the cornerstone of America's infrastructure. Information technology R&D is the cornerstone of tomorrow's infrastructure.

The "tire tracks" diagram illustrates time from concept to billion-dollar industry.




NSF support as a percent
of total federal support
of academic basic research
Physical Sciences
40%
Engineering
46%
Social Sciences
52%
Environmental Sciences
54%
Biology (ex. NIH)
66%
Mathematics
77%
Computer Science
86%
0
20
40
60
80