

# **U.S. Innovation and Information Technology Research and Development**

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The importance of information technology in enabling innovation and powering the new economy is well documented. Advances in computing and communications have led to significant improvements in product design, development and distribution for American industry, provided instant communications for people worldwide, and enabled new scientific disciplines like bioinformatics and nanotechnology that show great promise in improving a whole range of health, security, and communications technologies.

While economists had once struggled to see the payoff for industry in increased investments in IT -- economist Stephen Roach in 1986 noted this “productivity paradox” by showing that between 1975 and 1985, despite huge increases in organizational expenditures on IT, there were virtually no gains in organizational productivity over the period (King 2003) -- there is now a large body of research that points to just the opposite conclusion. Though computing power had not yet matured enough by 1985 to make a measurable impact on the economic bottom line, by 1995, hardware, software, and peripherals -- as well as the modifications to organizational practices necessary to best make use of that computing power -- had matured sufficiently to impact the productivity statistics in a meaningful way. (Atkinson, McKay 2006) Indeed, 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. (Jorgenson, Ho, Stiroh 2003)

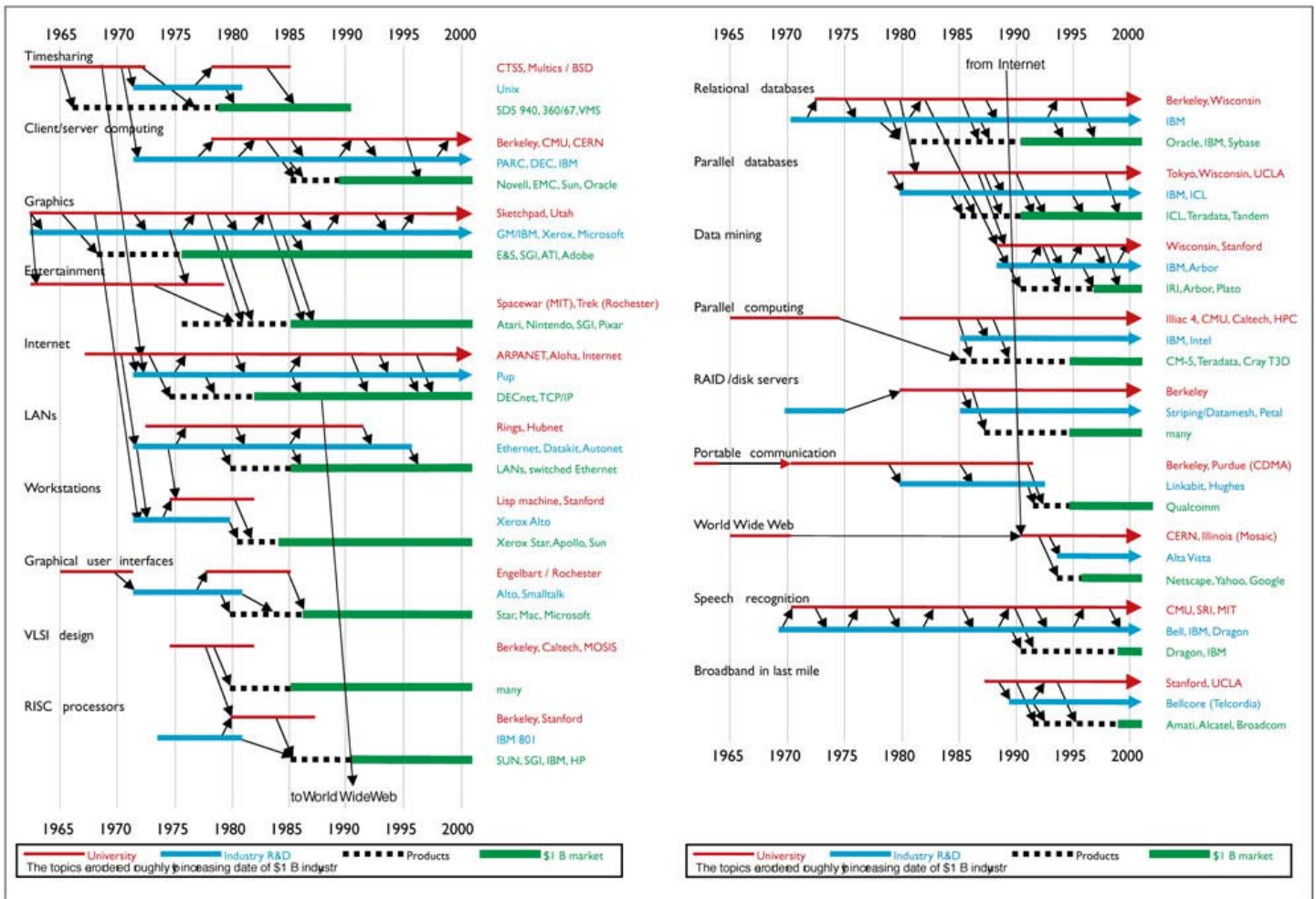
In *Digital Prosperity: Understanding the Economic Benefits of Information Technology Revolution* (2007), authors Robert D. Atkinson and Andrew S. McKay do a very admirable job of surveying the available research on IT’s impact on the new economy, explaining the processes by which information technologies 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. They also note the ways IT drives innovation:

- IT gives researchers powerful new tools;
  - IT enables small firms to significantly expand R&D;
  - IT boosts innovation by giving users more of a role;
  - IT lets organizations better manage the existing knowledge of its employees.
- (Atkinson, McKay 46-48)

Information technology has changed the conduct of research. Innovations in computing and networking technologies are enabling scientific discovery across every scientific 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, visualize large and complex datasets, and collect and manage massive amounts of data.

But equally important to the role IT plays in enabling innovations in industry and in the other scientific disciplines is the role of the research and development (R&D) ecosystem in enabling innovations within IT. This paper will focus on a key element -- perhaps the key element -- of that process: the involvement of universities, industry and the federal government in IT R&D.

### The Ecosystem that Gives Birth to New Technologies



Source: From [6], reprinted with permission from the National Academy of Sciences, courtesy of the National Academies Press, Washington D.C. © 2003.

A significant reason for the dramatic advance in computing technology and the subsequent increase in innovation and productivity is 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,” according a 1995 report by the National Research Council. That report, and a subsequent 1999 report by the President’s Information Technology Advisory Committee (PITAC), emphasized the “spectacular” return on the federal investment in long-term IT research and development.

The 1995 NRC report, *Evolving the High Performance Computing and Communications Initiative to Support the Nation's Information Infrastructure*, included a compelling graphic illustrating this spectacular return. The graphic was updated in 2002 and is reproduced above. (See figure 1.)

It is worth a moment to consider the graphic. The graphic charts the development of technologies from their origins in industrial and federally-supported university R&D, to the introduction of the first commercial products, through the creation of billion-dollar industries and markets. The original 1995 report identified 9 of these multibillion-dollar IT industries (the categories on the left side of the graphic). Seven years later, the number of examples had grown to 19 – multibillion-dollar industries that are transforming our lives and driving our economy.<sup>1</sup>

The graphic also illustrates the complex interplay between federally-supported university-based research and industrial R&D efforts. In some cases, such as reduced instruction set computing (RISC) processors (a chip architecture that forms the basis for processors used by Sun, IBM, HP, and Apple, and has significantly influenced all microprocessor design) and RAID disk servers (“redundant arrays of inexpensive disks”), the initial ideas came from industry, but government-supported university research was necessary to advance the technology. In other cases, such as timesharing, graphical user interfaces, and the internet, the ideas originated in the universities long before they matured to a point where subsequent research by industry helped move the technologies towards commercialization. In each example, the industry/university research relationship has been complementary. University research, focused as it is on fundamental questions and long-term problems, does not supplant industry research and development. And industry, which contributed \$203 billion in 2004 in overall R&D geared primarily towards short-term development, does not supplant university research.

This is an important point that bears some development. The great majority of industry-based research and development is of a fundamentally different character than university-based research. Industry-based research and development is, by necessity, much shorter term than the fundamental research performed in universities. It tends to be focused on product and process development, areas which will have more immediate impact on business profitability. Industry generally avoids long-term research because it entails risk in couple of unappealing ways. First, it is hard to predict the outcome of fundamental research. The value of the research may surface in unanticipated areas. Second, fundamental research, because it is published openly, provides broad value to all players in the marketplace. It is difficult for any one company to “protect” the fundamental knowledge gleaned from long-term research and capitalize on it without everyone in the marketplace having a chance to incorporate the new knowledge into their thinking. Those companies that do make significant fundamental research investments tend to be the largest companies in the sector. Their dominant position in the market insures that they

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<sup>1</sup> The National Academies' Computer Science and Telecommunications Board is in the process of updating the graphic yet again to incorporate additional billion-dollar sectors that have been spawned since the 2002 update, including Search and Social Networking (and perhaps Online Digital Video).

benefit from any market-wide improvement in technology basic research might bring. But, even with that advantage, the investment of companies like Microsoft and Intel in fundamental research remains a small percentage of their overall IT R&D investment (in Microsoft's case, it's estimated at around 5 percent of the company's R&D budget), and many companies of equivalent size (Oracle, Dell, Cisco) don't invest in long-term R&D at all.

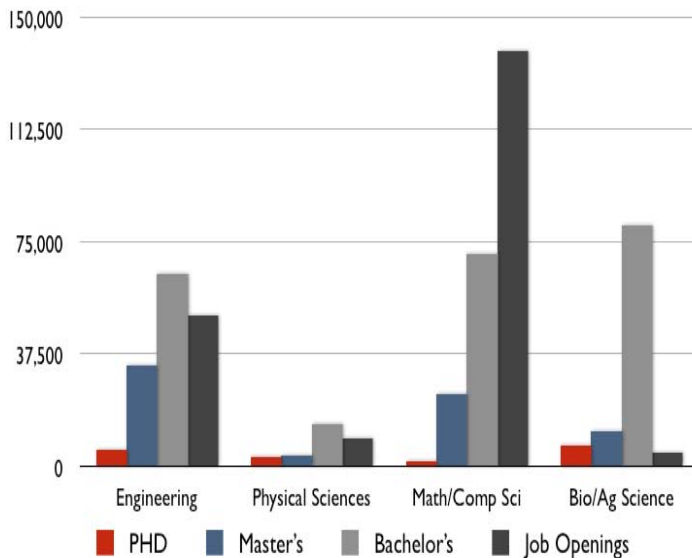
The complex nature of figure 1 also illustrates one other important characteristic of the IT R&D ecosystem – it is very interdependent. Note that the arrows that show the flow of people and ideas move not only between industry, university and commercial sectors, but between subfields as well, sometimes in unanticipated ways. Developments in internetworking technologies led to the development of the Internet and World Wide Web (and the rise of Yahoo and Google), but also to developments in Local Area Networking and Workstations. Work on timesharing and client and server computing in the 1960s led to the development of e-mail and instant messaging. In addition, this interdependence increasingly includes subfields beyond traditional IT, helping enable whole new disciplines like bioinformatics, optoelectronics, and nanotechnology.

Perhaps the most noteworthy aspect of the graphic is its illustration of the long incubation period for these technologies between the time they were conceived and first researched to the time they arrived in the market as commercial products. In nearly every case, that lag time is measured in decades. This is the clearest illustration of the results of a sustained, robust commitment to long-term, fundamental research. The innovation that creates the technologies that drive the new economy today is the fruit of investments the federal government made in basic research 10, 15, 30 years ago. Essentially every aspect of information technology upon which we rely today –the Internet, web browsers, public key cryptography for secure credit card transactions, parallel database systems, high-performance computer graphics, portable communications such as cell phones, broadband last mile...essentially every billion-dollar sub-market – is a product of this commitment, and bears the stamp of federally-supported research.

One important aspect of federally-supported university research that's only hinted at in the flow of arrows on this complex graphic is that it produces people, as well as ideas. This is especially important given the current outlook for IT jobs in the coming decade. Despite current concerns about off shoring and the end of the IT boom times, the U.S. Bureau of Labor Statistics this year released projections that continue to show a huge projected shortfall in IT workers over the next 10 years.



## Annual Degrees (2004) and Average Job Openings in Broad S&E Fields (2006-2016)



Degree data from National Science Foundation, Science and Engineering Degrees, 1966-2004.  
Jobs Data from Bureau of Labor Statistics, November 2007 Monthly Labor Review.

As figure 2 illustrates, the vast majority of the entire projected workforce shortfall in all of science and engineering is in information technology. These are jobs that require a Bachelors-level education or greater. Continued support of university research is therefore crucially important in keeping the fires of innovation lit here in the U.S.

### Important Characteristics of Federal Support

The current program coordinating the U.S. federal government's investments in IT R&D is called the Networking and Information Technology Research and Development program (NITRD). Currently, NITRD consists of \$3.3 billion in IT R&D funding spread across 13 federal agencies, coordinated by the Interagency Working Group on Information Technology Research and Development of the National Science and Technology Council. NITRD is the successor of the High Performance Computing and Communications Program established by Congress in 1991 in the High Performance Computing and Communications Act.<sup>2</sup>

Through the NITRD program, the participating agencies coordinate research in eight "Program Component Areas" (PCAs): High End Computing Infrastructure and Applications; High End Computing Research and Development; Human Computer Interaction and Information Management; Large Scale Networking; Software Design and Productivity; High Confidence Software and Systems; Social, Economic and Workforce

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<sup>2</sup> Participating agencies include: NSF, which serves as the lead NITRD agency; Agency for Healthcare Research and Quality (AHRQ), Defense Advanced Research Projects Agency (DARPA), National Security Agency (NSA), Department of Defense Service Research Organizations; Department of Defense Office of the Secretary of Defense (OSD), Department of Energy (DOE) National Nuclear Security Administration (NNSA), DOE Office of Science, Environmental Protection Agency (EPA), National Aeronautics and Space Administrations (NASA), National Institutes of Health (NIH), National Institute of Standards and Technology (NIST), National Oceanographic and Atmospheric Administration (NOAA), National Archives and Records Administration (NARA), and the Department of Homeland Security (DHS).

Implication of IT; and Cyber Security and Information Awareness. Given the structure of the NITRD program, coordination can prove difficult, however. Though each agency is represented within the Interagency Working Group on IT R&D, the IWG has no budget authority over any of the participating agencies. Each agency controls its own budget and sets its own goals for IT R&D spending exclusively on the perceived appropriateness of that funding to the agency's mission. In practical terms, this means the IWG function in NITRD is largely one of information sharing between agency representatives over what the agencies plan to do, not an opportunity to plan and perhaps achieve a more productive, efficient use of federal dollars to advance IT innovation.

As a result, there tends to be a sharp bias in the federal IT R&D portfolio towards short-term, application-oriented development -- a fact noted in the most recent review of the NITRD program by the President's Council of Advisors for Science and Technology (PCAST)<sup>3</sup>. So-called mission agencies -- like the National Oceanic and Atmospheric Administration (NOAA) or the National Aeronautics and Space Administration (NASA) -- tend to invest in applications geared to their respective missions, while leaving the long-term research to research-focused agencies like NSF and the Defense Advanced Research Projects Agency (DARPA). However, recent changes in research policy at DARPA have altered this productive IT R&D ecosystem in ways that cause great concern in the IT R&D community.

### **The Changing IT R&D Ecosystem Threatens U.S. Innovation Leadership**

The two dominant federal agencies in the development of the discipline of computing and the resulting innovation in IT have been the U.S. National Science Foundation (NSF) and DARPA. The fact that the agencies have had two significantly different approaches to funding IT R&D has been an overall benefit to the discipline. Historically, NSF has focused on funding smaller awards to the individual investigator; in the process ensuring a broad range of research in the field was performed. DARPA, created in response to the Soviet launch of Sputnik and charged with insuring the nation was never caught "flat-footed" by a technologically superior adversary again, has historically focused on larger awards and building communities of researchers to address critical research problems -- creating centers of excellence, many of which formed the basis of some of the top computer science departments in the country. In addition, funding opportunities at other mission-oriented agencies -- NASA, Department of Energy, Office of Naval Research, and the Air Force Research Labs -- meant university researchers had a number of possible outlets for their ideas, and consequently, many good ideas that may have otherwise gone unfunded found their way into the knowledge base.

But in addition to a diversity of funding sources, the discipline (and, by extension, the nation) has been well-served by especially visionary program managers, especially at DARPA, drawn from university and industrial research labs who knew the discipline well and were given the flexibility to take risks with the research they supported with their

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<sup>3</sup> *Leadership Under Challenge: Information Technology R&D in a Competitive World*. President's Council of Advisors on Science and Technology, August 2007.

program funds. As the National Research Council noted in the 2002 *Innovation in Information Technology* report:

This style of funding and management allowed researchers room to pursue new venues of inquiry. The funding style resulted in advances in areas as diverse as computer graphics, artificial intelligence, networking, and computer architecture. As that experience illustrates, because unanticipated outcomes of research are so valuable, federal mechanisms for funding and managing research need to recognize the inherent uncertainties and build in enough flexibility to accommodate midcourse changes.

Unfortunately, there is significant concern building within the academic computing research community that DARPA has lost much of what made it so important to the discipline by adopting policies that discourage university participation in defense-related IT R&D. Of particular concern is DARPA's recent focus on shorter-term research efforts, its implementation of a "go/no go" decision matrix for DARPA funded research projects, the classification of research on certain topics (for example, cyber security), and restrictions on the participation of foreign nationals (e.g., U.S. graduate students who are not U.S. citizens).

The idea of "scheduling" breakthroughs or demonstrable results on 12-month timelines results in research that is evolutionary instead of revolutionary, according to many within the research community, with potential grantees only proposing research they can be sure will deliver results within the shorter timeframe. This concern was also echoed in a report on the state of the U.S. Cyber Security R&D portfolio titled *Cyber Security R&D: A Crisis of Prioritization* by PITAC in 2005.

PITAC also raised concerns about the growing use of classification in DARPA-funded research. There are, of course, important reasons for classifying federal research, especially when it is clear that the research might reveal our capabilities or vulnerabilities. However, the committee noted that there are real costs – including that the research is unavailable for public dissemination and scrutiny, and that many university researchers, arguably some of the best minds in the country, are no longer able to contribute to the work. In the case of classifying Defense Department cyber security research, there is another significant cost to bear as well. The military (and the government overall) has a huge dependence on the nation's commercial infrastructure, but classifying the research in information security means that it is largely unavailable for use in protecting this commercial infrastructure.

The retreat of DARPA from funding fundamental computing research at U.S. universities has left a hole in the overall federal IT R&D portfolio that other participating agencies have yet to fill. As a result, the only agency funding long-term, basic computer science research to any significant degree is NSF, which noted in its FY 2008 budget request that it funds 86 percent of all federal obligations for basic computer science research in U.S. universities. The agency is beginning to show the strain of being the only "game in

town,” with proposal rates up significantly and award rates recently well below the Foundation averages.

In its report on the NITRD program in 2007, PCAST emphasized this concern by noting that the most critical need in the program is to “rebalance the NITRD investment portfolio to include more long-term, large-scale, multidisciplinary IT R&D.” The Committee also found that there are needed changes 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.

Failing to make these necessary changes to the IT innovation ecosystem threatens U.S. leadership in networking and information technology, the committee concluded. And a failure to lead in IT innovation may constrain the pace of U.S. innovation across the economy, imperiling many of the gains those innovations have enabled.

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