

**TESTIMONY OF
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**BEFORE THE HOUSE SCIENCE, SPACE AND TECHNOLOGY COMMITTEE
SUBCOMMITTEE ON RESEARCH AND SCIENCE EDUCATION**

**HEARING ON
APPLICATIONS FOR INFORMATION TECHNOLOGY
RESEARCH AND DEVELOPMENT**

FEBRUARY 14, 2013

Thank you Chairman Bucshon, Ranking Member Lipinski, and the other members of the Subcommittee, for this opportunity to discuss the Federal government's Networking and Information Technology Research and Development program. I am pleased to add my perspective on the Committee's questions, drawn from nearly 40 years as a member of the computing research community, my experience as the current chair of the Computing Research Association's (CRA) Computing Community Consortium (CCC), and as a member and chair of many Federal IT advisory committees – including, most recently, as the co-Chair of the Working Group of the President's Council of Advisors on Science and Technology (PCAST) to review the NITRD program.

In 2010, PCAST conducted a detailed assessment of the NITRD program, and in 2012 PCAST reviewed the progress of NITRD in implementing those recommendations.¹ As the co-chair of the PCAST Working Group that conducted that initial assessment, my testimony is informed by both reviews, though I present this testimony as an informed individual and not as a representative of PCAST.

What both the 2010 and 2012 reviews found, and indeed, what reviews over a 20-year period of the NITRD program and its predecessors have found, is that the research ecosystem supported by NITRD – a complex interplay between Federally supported researchers in U.S. universities and Federal labs, privately funded research and development in industry, and the flow of people and ideas between them – has been the primary factor in the U.S. becoming the world leader in information technology. And if the U.S. is to remain competitive in an increasingly competitive world, there is perhaps no sector more important in which to retain leadership than information technology.

Information Technology R&D Changes the World

The importance of this hearing's topic is hard to overstate. Advances in information technology are transforming all aspects of our lives. Virtually every human endeavor

¹ *Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology*, President's Council of Advisors on Science and Technology, December 2010 (<http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd-report-2010.pdf>) and January 2013 (<http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd2013.pdf>)

today has been touched by IT, including health care, energy, manufacturing, governance, national security, communications, the environment, commerce, education, employment, entertainment, science and engineering. We have doctors empowered by virtual agents that can help navigate tricky drug interactions or diagnose with data and not gut feeling alone, intelligent power grids with smart homes that work together to more efficiently utilize power resources, advanced robotics that enable the nation to retain a competitive manufacturing sector, government that works more transparently, a military that achieves dominance through information superiority, a network of friends reachable instantly anywhere around the globe, a planet wired with sensors feeding us real-time information about its health, the world's products available to us with the click of a mouse, instruction tailored to individual students and delivered from hundreds or thousands of miles away, the ability to be as productive from our couch at home as we are in our offices, movies and music and games that engage all our senses and take us to places no previous generation has seen, and a science and engineering enterprise primed with all the tools and data to enable discovery at a pace never before possible – all because of advances in computing systems, tools and services enabled by research and development.

Information Technology R&D Drives Our Prosperity

Advances in information technology are also driving our economy – both directly, in the growth of the IT sector itself, and indirectly, in the productivity gains all other sectors achieve from the application of IT. In fact, it is this latter effect that has had the most profound effect on the economy and the Nation's competitiveness. Across every sector of the economy, businesses large and small utilize IT systems, tools and services to improve their labor productivity, boost their operational efficiency and increase their economic output to an unprecedented extent. Large companies like Walmart and UPS have used the tools of IT to track and manage inventory on a minute-by-minute basis. Companies like Ford and Procter & Gamble use high-performance computing to design super-efficient automobiles, or even model the airflow over potato chips on a production line to minimize breakage and loss. Small manufacturers use IT to do virtual prototyping, avoiding costly prototype construction and allowing them to compete with much larger firms for lucrative manufacturing contracts. Advances in IT empower U.S. businesses, augment their competencies, and enable them to compete in an increasingly global 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. (See Figure 2.)

Information Technology is the Dominant Factor in American S&T Employment

Given information technology's influence in so many sectors of our lives, it should not be surprising that demand for IT workers is strong. The latest monthly hiring figures bear this out: of the 157,000 new jobs added to the economy in January, more than 22,000 were in IT fields.² Indeed, as the 2010 PCAST review of the NITRD program noted, *“all indicators – all historical data, and all projections – argue that [Networking*

² <http://www.infoworld.com/t/it-jobs/tech-jobs-account-14-percent-of-hiring-in-january-212267>

and Information Technology (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." Bureau of Labor Statistics projections indicate that more than 60 percent of all new jobs in all fields of science and engineering in the current decade will be for computing specialists. I share PCAST's belief that increasing the number of graduates in IT fields at all levels should be a national priority, and believe that the NITRD program ought to increase its focus on computer science education, from kindergarten through higher education, as one way to help meet that goal.

Federal Support is a Key Part of the Vibrant Ecosystem that Drives IT Innovation

The advances in IT that have had such a profound effect on every aspect of our lives are driven by innovation that is the product of a vibrant research ecosystem – an ecosystem comprised of university research programs, industrial research labs, Federal research labs, industrial development organizations, and the people and ideas that flow between them. The National Research Council has called this *"an extraordinarily productive interplay"* and the President's Information Technology Advisory Committee (PITAC) emphasized the *"spectacular return"* on the Federal investment made as part of this ecosystem.

The National Research Council's Computer Science and Telecommunication Board created a graphic that attempts to visualize this complex ecosystem. Known colloquially as the "Tire Tracks Diagram," this graphic is worth careful consideration. It was first created in 1995, updated in 2003, and updated again and re-conceptualized in 2012. (See Figure 1.)

The diagram is really a timeline, tracking the growth of different sectors of the IT economy. It has three lines for each subsector of the IT industry: a red line that indicates when research was performed in universities (largely supported by the Federal government), a blue line in the middle that shows when industrial research and development organizations were working in the space (largely with private sector funding), and a dotted black line that indicates when the first product was introduced in that sector. Where that dotted line turns solid green indicates when that became a billion-dollar market sector. Where the line thickens, it notes a \$10 billion+ market sector. The arrows on the diagram indicate the flow of people and ideas between the sectors. (Each arrow refers to a specific, documented flow.) Above the lines are some of the multi-billion-dollar companies that resulted.

The diagram shows a number of key aspects of the path from research to major market sector:

1. Research often takes a long time before it pays off. In a number of cases illustrated on the diagram, the earliest research takes place more than 15 years before the introduction of the first product.

2. Research often pays off in unanticipated ways. Developments in one sector often enable advances in others, often serendipitously.
3. Most importantly, every one of these multi-billion-dollar IT industry sectors has a clear relationship to Federal research investment. Research in universities does not supplant work done in industry, and vice-versa.

This point deserves amplification. The vast majority of industry R&D is *development* – the engineering of the next version of a product. This is entirely appropriate, but such work is of a fundamentally different character than Federally-sponsored university-based research. Industry-based R&D tends to be focused on product and process development, areas that will have more immediate impact on business profitability. Industry generally avoids long-term research because it entails risk in several unappealing ways. First, as the diagram illustrates, 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 investments in fundamental research are few and far between, and tend to be the largest companies in the sector. Their dominant position in the market increases the likelihood that they benefit from any market-wide improvement in technology that fundamental research might bring. And even at these companies, the investment in fundamental research is a small fraction of overall R&D investment. Microsoft is among the IT companies that invest the largest proportion of their R&D expenditures on research looking out more than one product cycle. Microsoft Research is a tremendous national asset. But Microsoft’s investment in Microsoft Research was estimated by PCAST to constitute less than 5% of the company’s total R&D. At almost all other companies, the investment that looks out more than one product cycle is far less. University research does not supplant industry research, or vice-versa.

4. The research ecosystem is fueled by the flow of people and ideas back and forth between academia and industry. This robust ecosystem has made the U.S. the world leader in information technology.

Each one of the multi-billion-dollar sectors illustrated on the “Tire Tracks Diagram” bears the clear stamp of Federal investments – investments that have demonstrated extraordinary payoff in the explosion of new technologies that have touched every aspect of our lives, and in the economic benefits of the creation of new industries and literally millions of new jobs.

An example might be instructive here. Apple’s iPad is a seemingly miraculous device. Available for about \$300, it’s a sleek, thin little slab of glass and metal that sits darkly in a purse or a pocket, then comes to life with a button push and a swipe of a finger, quickly figures out where it is, and connects itself to the largest collection of humanity’s

knowledge ever assembled. It's a remarkable confluence of technologies – processing capability powerful enough to have appeared on the list of the world's fastest supercomputers less than 20 years ago, a sensor suite (global positioning system, compass, accelerometer, microphone, camera, light sensor) robust enough to allow it to know where it is and what it's looking at, and an interface revolutionary in its ease of use. These technologies have enabled some truly game-changing capabilities – applications that allow turn-by-turn directions, or the ability to translate signs in a foreign language just by pointing its camera at them, or truly high-speed, ubiquitous connectivity to the power of the Internet, instantly and almost anywhere in the world.

What Apple has managed to do to bring these technologies together and meld them in a seamless way to enable these applications has been nothing short of remarkable. But none of the technologies originated with Apple. Without exception, they have their roots in early-stage scientific research, and all bear the stamp of Federal support.

Take, for example, the revolutionary multi-touch iPad interface – the pinch-to-shrink, swipe-to-scroll, twist-to-rotate gestures that make a tablet like the iPad intuitive and very easy to use. All were born out of university research, largely funded by the Federal government, conducted as early as the late 1960s and early 1970s. In fact, in 1998, researchers at the University of Delaware, whose work had earlier been enabled by research funding from the National Science Foundation, established a company called FingerWorks to market an early touch-screen keyboard based on their research. In 2005, Apple bought the company and its technology, then adapted it for the first iPhone.

A similar case can be made for the processor – the brain of the device. Microprocessors have their roots in the design of the original integrated circuit back in 1958, by a young Texas Instruments engineer named Jack Kilby. But it's a long path from that original design to the modern chip that powers the iPad. Industry research at TI and Fairchild, and later at IBM, Intel and others, was obviously important in moving development along, but just as important was research at U.S. universities – research on Reduced Instruction Set Computing (RISC) and Microprocessor without Interlocked Pipeline Stages (MIPS) technologies, as well as Very-Large-Scale Integration (VLSI) design methodologies and tools, the process of creating integrated circuits by combining thousands of transistors into a single chip, which put computer design in the hands of computer system architects (and graduate students) rather than only in the hands of engineers and technicians in costly chip fabrication plants. Federal investment in research (through DARPA and increasingly NSF) and government-industrial partnerships like SEMATECH were crucial in catalyzing research across institutions and accelerating the pace of innovation; work at universities in particular helped generate the people and ideas that fueled industry's advancements.

The iPad's GPS sensor can trace its history back even further – to the 1930s and work by the American physicist I. I. Rabi on magnetic resonance. His work, sponsored by the Navy, for which he won the Nobel Prize in 1944, led to the development of Magnetic Resonance Imaging, which has revolutionized medicine, and to work in 1949 by Norman Ramsey on atomic clocks, for which he won the Nobel Prize in 1989. The

super-accurate clocks Ramsey developed with grants from the U.S. military, based on the vibrations of a Cesium atom, are accurate to within one-billionth of a second. A constellation of these super-accurate clocks orbiting the earth on satellites enables devices on earth, such as nuclear submarines or cruise missiles, to know their location to within one foot anywhere on the planet. They also enable an amazing array of location-aware services on devices like the iPad that help consumers navigate through strange cities, find the best burger place within walking distance, or even recover their iPad if it is stolen.

It is possible to describe similar lineage for all the other key technologies in the iPad. This is not to diminish the accomplishment of Apple – on the contrary, what Apple has done has been to blend these technologies into a harmonious whole in a way that perhaps only Apple could do. But it highlights the crucial role of early-stage research, in many cases supported by the Federal government (and often *only* by the Federal government), in enabling world-changing innovation.

Incidentally, the history of the “Tire Tracks Diagram” is also telling in terms of continuing payoff of these investments. The first version of the diagram developed in 1995 noted nine billion-dollar-plus sectors. Eight years later the diagram was updated to include ten additional sectors. The latest version included so many new sectors that the authors were forced to aggregate them for clarity. Today, the eight biggest U.S. IT companies alone account for nearly \$700 billion in annual revenue.³

The history of the “Tire Tracks Diagram” also illustrates clearly that information technology is a field of continuous, rapid innovation and growth, often in directions that are difficult to predict. Many of the multi-billion-dollar sectors added in the 2003 update were not anticipated at all by the authors of the original 1995 report; similarly with the 2012 update.

There is Tremendous Potential for – and Tremendous Need for – Further Breakthroughs

The history of innovation in computing is impressive, but the future potential and future need are even more compelling. Further advances in information technology are essential to our prosperity. Further advances in information technology also are essential for responding to our national and global challenges – challenges such as revolutionizing transportation, achieving personalized education and life-long learning, powering the smart grid, empowering the developing world, improving health care, enabling advanced manufacturing, increasing national and homeland security, driving advances in all fields of science and engineering. All these and more are compelling challenges that depend upon further research advances in IT.

³ Apple (\$156.5B), HP (\$120.3B), IBM (\$104.5B), Microsoft (\$73.7B), Dell (\$62.1B), Amazon (\$61.1B), Intel (\$53.3B), Google (\$50.1B)

Additional Investment is Needed in Many Areas of IT R&D that are Crucial to National Priorities and National Competitiveness

Much of the focus of the Federal effort in computing at the time of passage of the original High Performance Computing and Communications Act of 1991 (which established the modern NITRD program) was rightly on the importance of High Performance Computing to scientific discovery and national security. Today, however, many other aspects of IT have risen to comparable levels of importance. Among these are the interactions of people with computing systems and devices; the interactions between IT and the physical world; large scale data capture, management and analysis; systems that protect personal privacy and sensitive confidential information; scalable systems and networking; and software creation and evolution. PCAST emphasizes, and I agree, that the nation's performance on benchmarks of HPC should not be the primary measure of our IT competitiveness.

In its 2010 report *Designing a Digital Future*, PCAST focused attention on the role of advances in NIT in achieving America's priorities in areas including health, energy and transportation, national and homeland security, discovery in science and engineering, education, and digital democracy. PCAST identified three of these areas as "*particularly timely and important*." I support PCAST's recommendations. They called for:

- A national, long-term, multi-agency research initiative on NIT for health that goes well beyond the current national efforts 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.

PCAST then identified seven "NIT research frontiers" as being of particular importance: NIT and people, NIT and the physical world, large-scale data management and analysis, trustworthy systems and cybersecurity, scalable systems and networking, software creation and evolution, and high performance computing. While emphasizing the need for sustained investment in all of these areas, PCAST identified four as meriting increased investment:

- The fundamentals of privacy protection and protected disclosure of information.
- Human-machine and social collaboration and problem-solving.
- Fundamental research in data collection, storage, management, and automated large-scale analysis.
- Instrumenting the physical world.

In its 2012 review, PCAST noted many areas of progress by NITRD agencies in addressing key research challenges: "big data," NIT-enabled interaction with the physical world, health IT, and cybersecurity. PCAST concluded that these areas "continue to be important, and while there is noticeable progress on interagency coordination since 2010, these areas remain as critical focal points in 2012 and beyond.

Continued emphasis and even greater coordination is recommended.” I concur with this assessment.

PCAST then highlighted several other areas in which progress has been slower, but which are no less important:

- **Social Computing:** Collective human-NIT interactions such as social media, peer production, crowdsourcing and collective distributed tasks. The report emphasizes the need “to understand the technical effects on special areas, such as security, privacy, health, and scientific discovery” from these emerging social phenomena.
- **Privacy:** Important challenges include “how to realize the benefits of collective personal information without compromising the privacy of individuals, how to achieve cybersecurity and security more broadly without unnecessary disclosure of individual information, how to design systems to avoid unintended personal disclosure, how to empower individuals to assert their identity and also make informed decisions about voluntary disclosure, and how to use the science of privacy protection to inform policy decisions.”
- **Software:** PCAST noted that “predictable development of software that has the intended functionality and is reliable, secure and efficient remains as one of the most important problems in NIT.”
- **Educational Technology:** New educational technologies, such as auto-grading and online social collaboration, as well as new instructional approaches, have enabled an explosion in new models for education, from pre-K to college-level Massively Online Open Courses (MOOCs) to life-long learning. But assessment of the use of technology for education at all levels still needs research.
- **Energy and Transportation:** Work on achieving dynamic power management in applications from single devices to buildings to the power grid, low-power system and devices, and research relevant to surface and air transportation remain crucially important.
- **Scalable Systems and Networking:** Research to develop significant improvements in the efficiency of radio spectrum utilization, and work to promote the use of a nationwide infrastructure for spectrum monitoring that cuts across commercial, public safety, and DoD applications should remain a priority.
- **High-Performance Computing:** PCAST repeated its 2010 recommendation of “a substantial and sustained program of long-term, fundamental research on architectures, algorithms, and software for future generations of HPC.”

Importantly, for technical reasons, individual processors are no longer increasing in performance: since 2005, the trend has been “more processors” rather than “faster processors.” This requires entirely new approaches to software, scalable systems, and high performance computing. The field faces a dramatic set of research challenges if we are to continue to enjoy in the future the remarkable benefits that we have enjoyed in the past.

The Federal Government Needs High-level, Sustained, Expert Strategic Advice on IT

Another key recommendation contained in both the 2010 and 2012 PCAST reports, with which I strongly concur, is the call for the establishment of a “high-level standing committee of academic scientists, engineers, and industry leaders dedicated to providing sustained strategic advice in NIT.” Given the pace of innovation and change within the field, the challenge of its multi-disciplinary, problem-driven research, and the size and scope of the Federal investment, having sustained guidance from a free-standing, independent advisory committee seems crucial to NITRD’s success.

Computer Science is an Essential Component of Science, Technology, Engineering and Mathematics (STEM) Education

As I noted above, the workforce needs of the IT fields going forward demand a sustained effort to increase the number of students going into computing fields. National security needs will require that many of those students be American citizens. In addition, participants in many other workforce fields will need IT knowledge and skills. Making progress on this effort will require reversing trends not just in computing, but across the STEM disciplines. I am pleased that PCAST has called for the National Science and Technology Council’s Committee on STEM Education to exercise strong leadership to bring about fundamental changes in K-12 STEM education in the U.S. Among these changes has to be the incorporation of computer science as an essential STEM component. As they note, *“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.”* Groups such as Computing in the Core have expended a great deal of effort to get computer science recognized as a key part of the K-12 curriculum, but must be met with more acceptance if we are to meet the needs of our information-driven economy now and in the future.

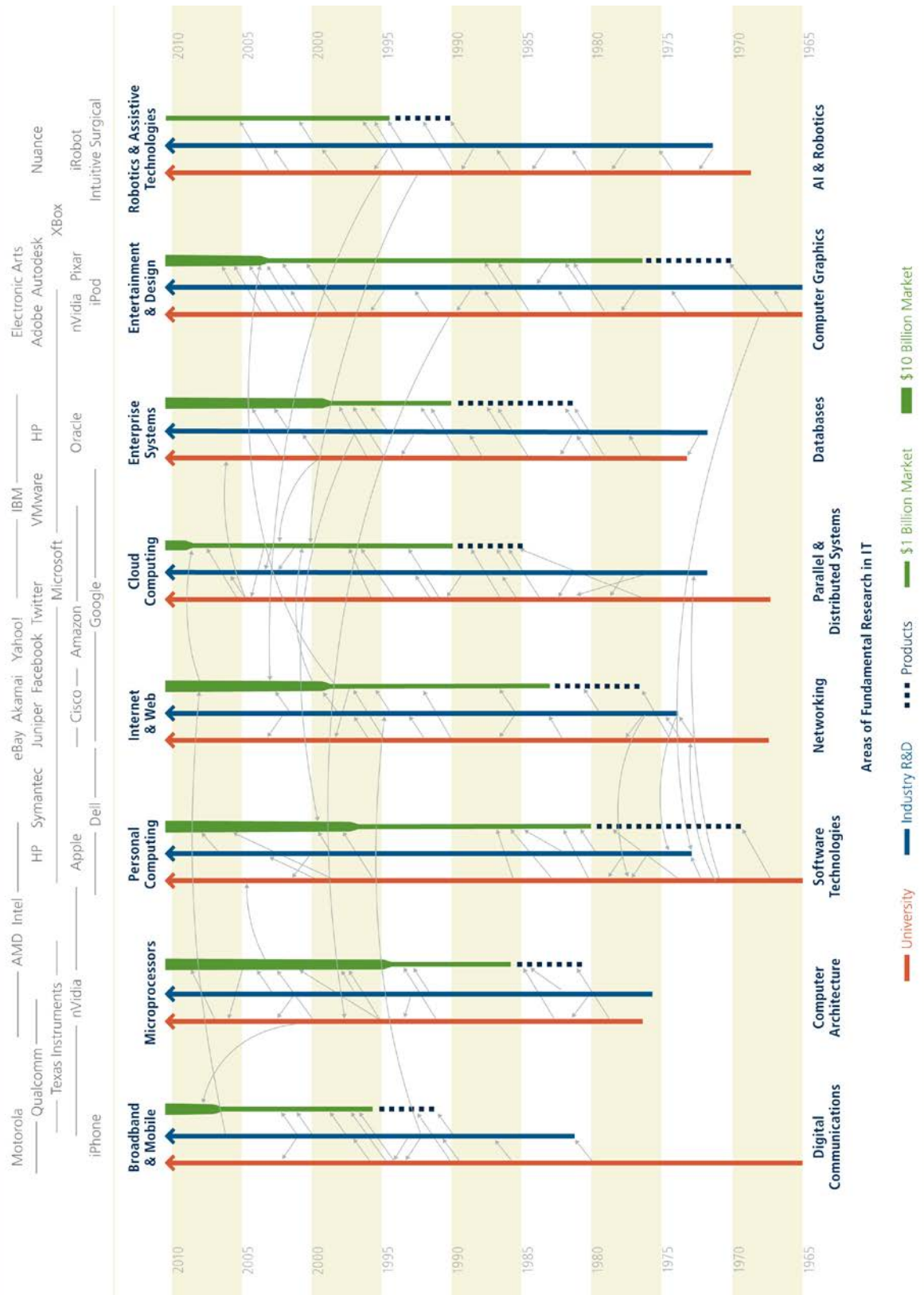
Conclusion: Federal Investment in Information Technology R&D Has Yielded, and Will Continue to Yield, Extraordinary Payoff

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. The payoff has been an explosion of new technologies that have touched nearly every aspect of our lives, and the creation of new industries and literally millions of new jobs.

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.

IT Sectors With Large Economic Impact



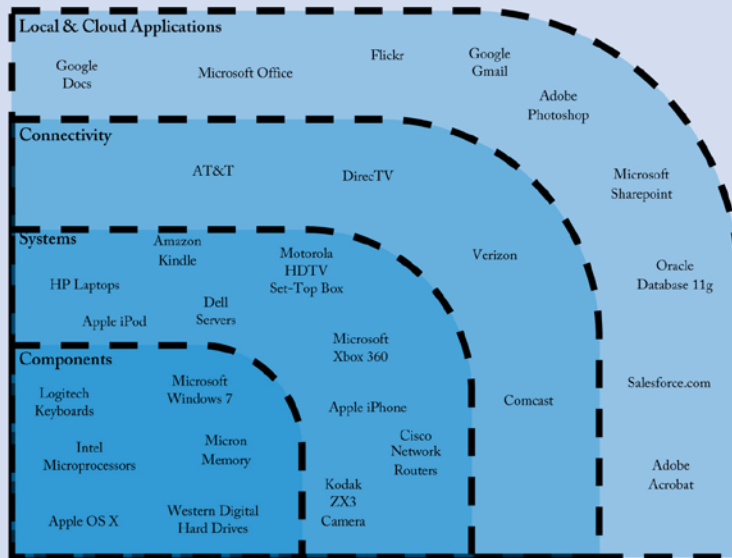
Source: *Continuing Innovation in Information Technology*, © 2012, The National Academies Press
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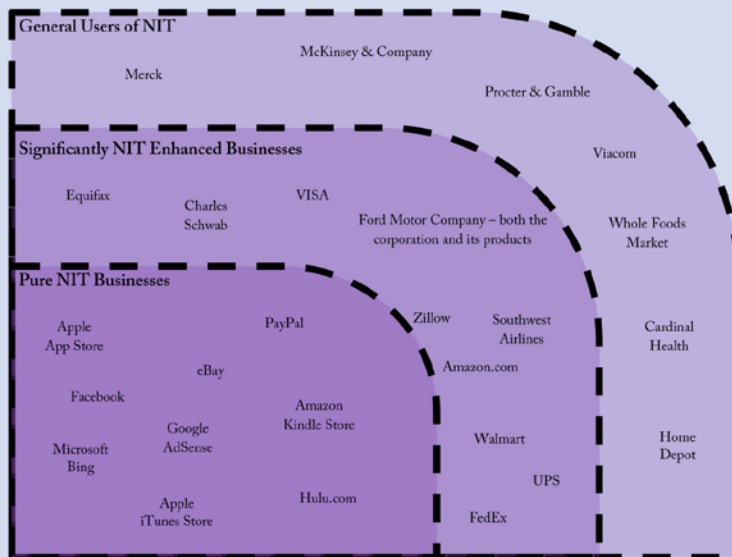
Figure 1

Reproduced from the NRC Computer Science & Telecommunications Board report *Continuing Innovation in Information Technology*, 2012; http://www.nap.edu/catalog.php?record_id=13427

The Pervasiveness of NIT from the Consumer Perspective



These examples of NIT products and services illustrate their ubiquity and show how advances in particular aspects of NIT influence a broad swath of the tools that we use at work and at home. NIT components, which include hardware and lower-level software, combine to create cohesive, unified NIT products, most of which are not thought of as computers per se. Digital connectivity links systems, enabling transparent choice between local and cloud applications for a wide variety of purposes.



These examples show how companies are embracing NIT at a relentless pace. Pure NIT businesses focus on providing digital services and products. Significantly NIT enhanced businesses use NIT advances to greatly improve their services and products. General users of NIT include consumers and firms that utilize NIT in their daily workflows.

Figure 2

Reproduced from the PCAST report *Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology*, December 2010;
<http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd-report-2010.pdf>