

**APPLICATIONS FOR INFORMATION  
TECHNOLOGY RESEARCH & DEVELOPMENT**

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**HEARING**  
BEFORE THE  
SUBCOMMITTEE ON RESEARCH  
COMMITTEE ON SCIENCE, SPACE, AND  
TECHNOLOGY  
HOUSE OF REPRESENTATIVES  
ONE HUNDRED THIRTEENTH CONGRESS

FIRST SESSION

THURSDAY, FEBRUARY 14, 2013

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TECHNOLOGY RESEARCH & DEVELOPMENT**

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**THURSDAY, FEBRUARY 14, 2013**

HOUSE OF REPRESENTATIVES,  
SUBCOMMITTEE ON RESEARCH  
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,  
*Washington, D.C.*

The Subcommittee met, pursuant to call, at 2:01 p.m., in Room 2318 of the Rayburn House Office Building, Hon. Larry Bucshon [Chairman of the Subcommittee] presiding.

LAMAR S. SMITH, Texas  
CHAIRMAN

EDDIE BERNICE JOHNSON, Texas  
RANKING MEMBER

**Congress of the United States  
House of Representatives**

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

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Subcommittee on Research Hearing

*Applications for Information Technology Research & Development*

Thursday, February 14, 2013

2:00 p.m. – 4:00 p.m.

2318 Rayburn House Office Building

Witnesses

**Dr. Kelly Gaither**, Director, Visualization Lab, Texas Advanced Computing Center, University of  
Texas, Austin

**Dr. Kathryn McKinley**, Principal Researcher, Microsoft

**Dr. Ed Lazowska**, Bill and Melinda Gates Chair in Computer Science and Engineering, University of  
Washington

U.S. HOUSE OF REPRESENTATIVES  
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HEARING CHARTER

*Applications for Information Technology Research & Development*

Thursday, February 14, 2013  
2:00 p.m. – 4:00 p.m.  
2318 Rayburn House Office Building

**Purpose**

On Thursday, February 14, 2013, the Subcommittee on Research will hold a hearing to show the practical applications and benefits of the Networking and Information Technology Research and Development (NITRD) program and its significance to U.S. competitiveness.

**Witnesses**

- Dr. Kelly Gaither, Director, Visualization Lab, Texas Advanced Computing Center, University of Texas, Austin
- Dr. Kathryn McKinley, Principal Researcher, Microsoft
- Dr. Ed Lazowska, Bill and Melinda Gates Chair in Computer Science and Engineering, University of Washington

**Overview**

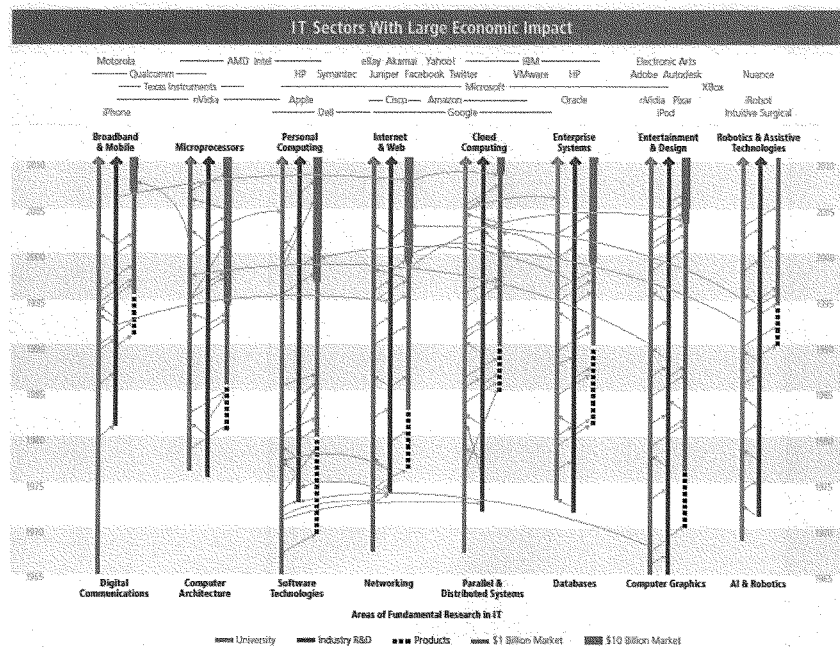
The United States has been the world leader in networking and information technology (NIT). Federal support for research and development (R&D) in NIT originally stemmed from an interest in and the challenge of developing computers capable of addressing complex problems, primarily those focused on national security and hi-end applications. Over the past decades, however, federal spending for NIT R&D has encompassed a broad array of technologies, from digital libraries to cloud computing. The eventual commercial applications for such federally-funded R&D has fundamentally changed the way modern-day Americans work and live.

Additionally, R&D in NIT provides a greater understanding of how to protect essential systems and networks that support fundamental sectors of our economy, from emergency communications and power grids to air-traffic control networks and national defense systems. NIT R&D works to prevent or minimize disruptions to critical information infrastructure, to protect public and private services, to detect and respond to threats while mitigating the severity of and assisting in the recovery from those threats, in an effort to support a more stable and secure nation.

Originally authorized in the High-Performance Computing Act of 1991, the NITRD program is the main R&D investment portfolio of 15 federal member agencies in networking, computing, software, cyber security and related information technologies totaling over \$3.7 billion in FY2013 (with the National Science Foundation being the principal contributor with

over \$1.1 billion of that total). Other federal agencies participate in program activities beyond the 15 member agencies. The NITRD program supports a number of research areas, including big data, cyber physical systems, cyber security and information assurance, health technology, high performance computing and large scale networking.

Federally funded NIT research and industry are tightly linked to innovation. The President's Council of Advisors on Science and Technology (PCAST) recently released the following updated "Tire Tracks" diagram in their January 2013 report titled *Designing A Digital Future: Federally Funded Research and Development in Networking and Information Technology* (See: <http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd2013.pdf>)





Chairman BUCSHON. The Subcommittee on Research will come to order. Good afternoon. Welcome to today's hearing entitled "Applications for Information Technology Research & Development." In front of you are packets containing the written testimony, biographies, and truth-in-testimony disclosures for today's witness panel. I recognize myself now for five minutes for an opening statement. First, I want to welcome everyone today. This is my first hearing as the Chairman of the Research Subcommittee and I look forward to working with the Ranking Member, Mr. Lipinski, on this and many other issues in the 113th Congress.

The topic of this afternoon's hearing, "Applications for Information Research & Development," is important to our national security, global competitiveness, and technological innovation. This hearing will provide us with examples of practical applications and the benefits of federal investment in networking and information technology, or NITRD research.

The Networking and Information Technology Research and Development Program, or NITRD, was originally authorized in 1991 in the High Performance and Computing Act. It coordinates the networking and information R&D efforts of 15 federal agencies, including DHS, NASA, NIH, EPA, and the Department of Energy. The program is the main R&D investment portfolio of member agencies in networking, computing, software, cybersecurity, and related informational technologies totaling over \$3.7 billion in fiscal year 2013. R&D in NIT provides a greater understanding of how to protect essential systems and networks that support fundamental sections of our economy, from emergency communications and power grids to air traffic control networks and national defense systems.

NITRD works to prevent or minimize disruptions to critical information infrastructure to protect public and private services, to detect and respond to threats while mitigating the severity of and assisting in the recovery from those threats in an effort to support a more stable and secure Nation.

As technology rapidly advances, the need for NIT research and development continues to evolve. NITRD works to prevent duplicative and overlapping R&D efforts, thereby enabling more efficient use of brain power and resources while maintaining—while remaining good stewards of the taxpayers' money.

Today, our witnesses will share their professional perspectives on how NITRD applies to the quality of Americans' everyday lives. I would like to now recognize the Ranking Member, the gentleman from Illinois, Mr. Lipinski, for an opening statement.

[The prepared statement of Mr. Bucshon follows:]

PREPARED STATEMENT OF CHAIRMAN LARRY BUCSHON

First, I want to welcome everyone today. This is my first hearing as Chairman of the Research Subcommittee and I look forward to working with the Ranking Member, Mr. Lipinski, on this and many other issues in the 113th Congress.

The topic of this afternoon's hearing, Applications for Information Research & Development, is important to our national security, global competitiveness and technological innovation. This hearing will provide us with examples of practical applications and the benefits of Federal investment in networking and information technology R&D.

The Networking and Information Technology Research and Development program, or NITRD, was originally authorized in 1991 in the High Performance and Computing Act. It coordinates the networking and information R&D efforts of 15 Federal member agencies, including DHS, NASA, NIH, EPA and the Department of Energy. The program is the main R&D investment portfolio of member agencies in networking, computing, software, cyber security and related information technologies totaling over \$3.7 billion in FY2013.

R&D in NIT provides a greater understanding of how to protect essential systems and networks that support fundamental sectors of our economy, from emergency communications and power grids to air-traffic control networks and national defense systems. NIT R&D works to prevent or minimize disruptions to critical information infrastructure, to protect public and private services, to detect and respond to threats while mitigating the severity of and assisting in the recovery from those threats, in an effort to support a more stable and secure nation.

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Today our witnesses will share their professional perspectives on how NITRD applies to the quality of American's everyday lives.

Mr. LIPINSKI. Thank you, Mr. Chairman. I want to thank you for holding this hearing and also congratulate you on being named the Chair of this Subcommittee. I have been either Chair or Ranking Member of this Subcommittee now for three Congresses. I love this Committee and this Subcommittee. I look forward to working with you. I had a very good relationship with the Chair last Congress, and I think we could work very well together and get some good things done in these next two years. I am looking forward to that.

The House has passed bipartisan legislation reauthorizing the NITRD program in the past two Congresses. So I believe we can get something done again in this Congress. Hopefully, the third time is the charm with the Senate.

The most problematic issue threatening the NITRD program right now are the cuts and uncertainty in top-line R&D budgets. While authorizing NITRD wouldn't solve these problems, it would signal the government's continuing interest in investing in these critical research areas in a partnering with industry to help set R&D and workforce training priorities that prepare our nation for the future.

The NITRD program evolved from a federal program established under the High Performance Computing Act of 1991, as the Chairman said. That Act provided the funding that led to the development of Mosaic in 1993, the World Wide Web browser that made the Internet user friendly and led to its explosion in the 1990s. I am proud to note that Mosaic was created by a team of programmers at the federally funded National Center for Supercomputing Applications at the University of Illinois. Netscape founder Marc Andreessen, who was a leader of the Illinois team before launching his company, was quoted as saying "if it had been left to private industry, it wouldn't have happened, at least not until years later."

Without question, the 1991 Act sets the stage for a coordinated federal R&D investment strategy that has underpinned U.S. leadership in networking and information technology over the past 2 decades. In Illinois, that leadership in R&D is helping to complete work on a Blue Waters project, a petascale supercomputer that will maintain the University of Illinois' position at the forefront of high performance computing research.

But as with many other areas of R&D, we can no longer take for granted U.S. leadership in NIT. As noted by Dr. McKinley and his testimony, China, Japan—let me go back and—I think I may have said Mr.—make sure I said Dr. McKinley in her testimony—China, Japan, Germany, and several other countries are increasing their investments in NIT R&D and in their capacity to convert R&D into new commercial technologies.

As we heard from witnesses at a hearing on U.S. competitiveness last week, R&D no longer occurs in simple linear progression from basic research to commercial product. There may be a clear role for the government in basic research, including use-inspired basic research; and a clear role for industry in the last 1 to three years of product development work. But there are multiple gaps between those efforts. And our economy benefits exponentially when our R&D portfolio includes partnerships that facilitate collaboration among universities, national labs, and industry. This applies as much to NIT as to any other area of R&D. In fact, historically,

some of the most economically important public-private partnerships have been in the NIT sector.

We must also join forces in addressing NIT education and workforce challenges. While the Federal Government has a role here, I would like to hear our witnesses' input on that. This is also a problem that demands the attention of state and local government, as well as the private sector. As I have noted several times in the past, I am concerned about trends in outsourcing of even high skills jobs. At the same time however, we hear anecdotally of thousands of U.S. NIT jobs that go unfulfilled due to a lack of qualified applicants. There is no doubt we need to do a better job overall in preparing our students for jobs of today and in the future, and in particular, we need to graduate more computer science majors.

I hope the Chairman will allow me to go a little over time after I praised him at the beginning. Now, I don't have too much longer.

Finally, because PCAST discusses this topic in their latest review of NITRD, I want to bring up educational technology and the possible topic of discussion for this hearing. By that I mean R&D on technology to improve learning outcomes and increase access to high-quality education, including STEM education. One of the hottest topics today in higher education is Massively Open Online Courses, or MOOCs. Many of the MOOC courses are in computer science and engineering. I wonder how this is changing the NIT education landscape, as well as what the implications and opportunities are for education research. This is an also expansive enough topic on its own and maybe the Subcommittee would consider holding a separate hearing to look more carefully at these issues.

With that, I want to thank all the witnesses for being here today, in particular Dr. Lazowska, who is becoming an old hand at this by now. I look forward to all your testimony and yield back.

[The prepared statement of Mr. Lipinski follows:]

PREPARED STATEMENT OF RANKING MINORITY MEMBER DANIEL LIPINSKI

Thank you Chairman Bucshon for holding this hearing. And congratulations on being selected to Chair this Subcommittee.

The House has passed bipartisan legislation reauthorizing the NITRD program in the past two Congresses, so I believe that we can get something done again this Congress. Hopefully the third time is the charm for the Senate.

The most problematic issues threatening the NITRD program right now are the cuts and uncertainty in top-line R&D budgets. While reauthorizing NITRD wouldn't solve these problems, it would signal the government's continuing interest in investing in these critical research areas, and in partnering with industry to help set R&D and workforce training priorities that prepare our nation for the future.

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But as with many other areas of R&D, we can no longer take for granted U.S. leadership in NIT. As noted by Dr. McKinley in her testimony, China, Japan, Germany, and several other countries are increasing their investments in NIT R&D, and in their capacity to convert R&D into new commercial technologies. As we heard from witnesses at a hearing on US Competitiveness last week, R&D no longer occurs in a simple linear progression from basic research to commercial product. There may be a clear role for the government in basic research, including use-inspired basic research, and a clear role for industry in the last 1-3 years of product development work. But there are multiple gaps between those efforts, and our economy benefits exponentially when our R&D portfolio includes partnerships that facilitate collaboration among universities, national labs, and industry. This applies as much to NIT as to any other area of R&D. In fact, historically, some of the most economically important public-private partnerships have been in the NIT sector.

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With that, I want to thank all of the witnesses for being here today, and in particular Dr. Lazowska who is becoming an old hand at this by now. I look forward to all of your testimony.

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<sup>1</sup>Dr. McKinley cites 3,400 unfilled research and engineering positions at Microsoft alone.

Chairman BUCSHON. Thank you, Mr. Lipinski.

If there are Members who wish to submit additional opening statements, your statements will be added to the record at this point.

At this time, I would like to introduce our witnesses. Our first witness is Dr. Kelly Gaither. She is the Director of Visualization and a Senior Research Scientist at the Texas Advanced Computing Center. Additionally, she serves as the area Co-Director for Visualization and the National Science Foundation-funded XSEDE project. Dr. Gaither received her doctorate degree in Computational Engineering from Mississippi State University. Welcome.

Our next witness is Dr. Kathryn McKinley, who is a Principal Researcher at Microsoft and an Endowed Professor of Computer Science at the University of Texas at Austin. Dr. McKinley has a broad area of research interests, and her research group has produced numerous tools, algorithms, and methodologies are used in a variety of industrial settings. Dr. McKinley earned her B.A., M.S., and Ph.D. from Rice University. Welcome.

Our final witness today is Dr. Ed Lazowska. Mr. Lazowska holds the Bill and Melinda Gates Chair in Computer Science and Engineering at the University of Washington. He also serves as the Founding Director of the University of Washington eScience Institute and the Chair of the Computing Community Consortium. Dr. Lazowska has received national recognition for his research and leadership activities. Dr. Lazowska earned his Ph.D. from the University of Toronto. Welcome.

As our witnesses should know, spoken testimony is limited to five minutes each after which Members of the Committee will have five minutes each to ask questions. I now recognize Dr. Gaither to present her testimony.

**TESTIMONY OF DR. KELLY GAITHER,  
DIRECTOR, VISUALIZATION LAB,  
TEXAS ADVANCED COMPUTING CENTER,  
UNIVERSITY OF TEXAS, AUSTIN**

Dr. GAITHER. Thank you, Chairman Bucshon, Ranking Member Lipinski, and Members of the Subcommittee for this opportunity. I am here as the Director of Visualization and a Senior Research Scientist at the Texas Advanced Computing Center.

At TACC, our mission is to enable discoveries that advance science and society through the application of advanced computing technologies. We support thousands of researchers and partner with companies like Dell, Intel, Shell, Chevron, and BP to push the state of the art. Science can only advance if we continue to push the envelope.

Computational science or the application of computer simulations to scientific applications is the third pillar of 21st century science. Significant progress has been made in the last two decades because of federal investments in interdisciplinary teamwork. As an interdisciplinary researcher, I have been funded to work on projects like the visualization and data analysis of massive scale turbulent flow simulations—important because of its applications in aircraft and automobile design, energy, storm damage, and galaxy formation.

I am also the principal investigator for the largest visualization cluster in the world. With this project, we have enabled more than 619 researchers conducting large-scale computational science, and we have trained hundreds of people at institutions across the Nation. I am also the director of a visualization laboratory, home to one of the largest tile displays in the world. We have had more than 18,000 people come through those doors, many of which are K-12 students.

We are a country of innovators and this innovation must be fostered with significant investment and patience. The NITRD program gives us that funding for resources at a scale prohibited for individual institutions. With respect to funding opportunities in NITRD, let me first commend the efforts to create national programs with increasing focus on data. However, this should not be done to the exclusion of funding research and development and modeling, simulation, and visualization. It is imperative that we strive to build a balanced portfolio of funding opportunities.

We can see the evidence of a shift in the Nation's high-end computing strategy. The decrease in funding is not limited to the resources but extends to many of the underlying scientific applications and crucial software tools as well. This dip in funding is at odds with the increased need for high-end computing technologies and open science research.

How can we ensure a persistent pipeline to meet the Nation's IT needs? I graduated from high school in one of the poorest states in the Nation at a time when young women were not encouraged to go to college. I have been supported by federally-funded computational research dollars since I was 24 years old. I am the by-product of federal funding, and persistent funding at that. Without this funding, I would not have had the opportunities to participate in many of the interdisciplinary research projects that focus on solving some of society's most challenging issues. We need opportunities to educate students in interdisciplinary research and provide invaluable hands-on experience working with teams of researchers. We are lacking a thriving focus on research and development that is not driven by quarterly profit bottom line.

In closing, I would like to reiterate my appreciation for the invitation to speak to you today about the impact that the NITRD program has had in my research. To summarize, first, we must make significant continued investments in the NITRD program. As a researcher, I know that investments in research will keep us at the forefront of innovation. We must not shortchange our commitment and vision to continue the successes of those that have come before us.

Second, we must maintain a balanced portfolio of NITRD funding opportunities for researchers in computational science. We must find a way to continue to increase investment not to the exclusion of existing funding streams. It is a combination of efforts that is most likely to be fruitful.

And last, we must provide exciting opportunities to entice our students to stay in computational science. We must deal head-on with the brain drain that our universities are experiencing in undergraduate and postgraduate education. While there is no magic bullet that will solve this problem, it seems clear that a new ap-

proach is warranted. This new approach requires an investment in both curriculum development and student research to provide exciting opportunities for future generations of scientists.  
[The prepared statement of Dr. Gaither follows:]



**Written Testimony of  
Dr. Kelly Gaither  
Director of Visualization/Senior Research Scientist  
Texas Advanced Computing Center  
The University of Texas at Austin**

**Before the  
House Science, Space and Technology Committee  
Subcommittee on Research**

**Hearing on  
“Applications for Information Technology Research & Development”**

**February 14, 2013**

Thank you, Chairman Bucshon, Ranking Member Lipinski and members of the Subcommittee for the opportunity to testify before you today. In my capacity as Director of Visualization and Senior Research Scientist at the Texas Advanced Computing Center at The University of Texas at Austin, I have direct experience on the significant impact federal dollars have had on information technology research and development. I am speaking to you today as a researcher having worked at two interdisciplinary research centers: presently at the Texas Advanced Computing Center and, before that, at Mississippi State’s National Science Foundation Engineering Research Center supporting high-fidelity physics simulations over complex geometries.

We often hear that we live in the information age. To be more specific, we live in the data age. We are inundated with data in all aspects of our life, both personal and professional. Data is merely a delivery vehicle for what we are truly interested in – knowledge and information. The process by which we uncover this information is what drives my research. In my laboratory, we are dedicated to developing new methods for finding information in what is often an enormous amount of data. The tremendous processing capacity present in our visual cortex makes visualization, or the process by which we transform data to visual imagery, a powerful means for ferreting out information. This transformation requires an understanding of algorithm design, computational geometry, perception, computational science, analytics and cognitive processes.

Over the past twenty years, I have been fortunate to research and develop methods for visualizing data of fluid flow over aircraft, emerging storm systems, biological processes and K-12 decision making to name a few. This work is always done in an interdisciplinary format bringing together researchers from a variety of backgrounds with the expectation that meshing our collective expertise will provide us greater opportunities for advancing the state of the art in science.

**The Texas Advanced Computing Center**

At the Texas Advanced Computing Center, our mission is to enable discoveries that advance science and society through the application of advanced computing technologies. To fulfill this mission, we identify, evaluate, deploy, and support powerful computing, visualization, and storage systems and software. Helping researchers and educators use these technologies effectively, and conducting research and development to make these technologies more powerful, more reliable, and easier to use is at the forefront of what we do. Thousands of researchers each year use the computing resources available at TACC to forecast weather and environmental disasters such as the BP oil spill, produce whole-Earth simulations of plate tectonics, and perform other research relevant to the public at large. The center is supported by the National Science Foundation, The University of Texas at Austin, The University of Texas System, and grants from other federal agencies. As a leading resource provider in the NSF XSEDE project, TACC is one of eleven centers across the country providing leadership-class computing resources to the national research community. At TACC, we support thousands of projects for thousands of researchers across all aspects of science and engineering. We partner with companies like Shell, Chevron, and BP to push the state of the art, providing beneficial advancements to their science and engineering process as well. Over the past eleven years, TACC has trained a multitude of professional staff and students who now work at companies like Google, Intel, and Microsoft. Additionally, TACC outreach programs have trained researchers and provided computational resources to over a hundred universities.

**Science Only Advances if We Continue to Push the Envelope**

As stated in the 2005 report to the president, "Computational Science: Ensuring America's Competitiveness," computational science has become the third pillar of 21<sup>st</sup> century science<sup>1</sup>. This third pillar complements theory and physical experimentation, allowing scientists to explore phenomenon that are too big, small, fast, or dangerous to investigate in the laboratory. Computational science has made significant progress in the last two decades, but has only been able to do so because of federal investments, interdisciplinary teamwork, and leveraging the successes of researchers before us.

As a computational science researcher, focusing on visualization, I have been supported by funding under the NITRD vision since I was a graduate student. This funding facilitated my education, my professional growth, and by extension, the students and staff that have trained under me over the years. Without this funding, I would have left academic research to pursue opportunities that would have allowed me to be self-sufficient.

One example of the interdisciplinary research that I have been funded to work on is visualization and data analysis of massive scale turbulent flow simulations to track and understand small-scale features [1]. Turbulence, the most common state of fluid motion in nature and engineering, is a Grand Challenge problem for the physical and computer sciences and has applications in aircraft and automobile design, energy, storm damage

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<sup>1</sup> President's Information Technology Advisory Committee Report to the President,

and galaxy formation. Effectively simulating the wide range of non-linearly interacting three-dimensional fluctuations typical of applications requires the largest supercomputers in the world today. Understanding the geometric and dynamic descriptions of intense events in these simulations allows scientists to get closer to a more complete understanding of turbulent flows and more accurate models for engineering applications. The images shown in Figure 1 show the dramatic increase in data complexity as the size and scale grow from  $512^3$  to  $1024^3$  to  $2048^3$  to  $4096^3$ . Our interdisciplinary team of researchers worked together to develop new methods for classifying and tracking these minute scale features over time.

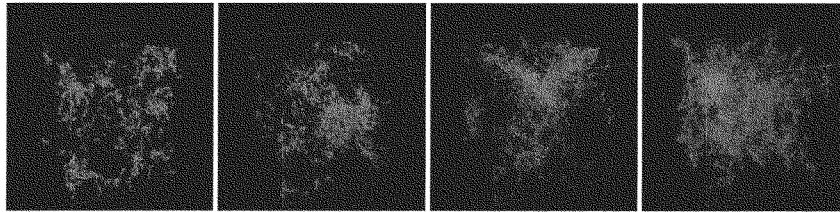


Figure 1: Visualizations showing increasing levels of complexity in the data as the size and scale of the turbulent flow increases.

I am also the principal investigator for the largest hardware-accelerated visualization cluster in the world, capable of producing visualizations of data on an unprecedented scale. This Longhorn team is also an interdisciplinary effort bringing together researchers from the University of Texas at Austin, the Scientific Computing and Imaging Institute (SCI) at the University of Utah, the Purdue Regional Visual Analytics Center (RVAC), the Data Analysis Services Group at the National Center for Atmospheric Research (NCAR), the University of California Davis (UC Davis) and the Southeastern Universities Research Association (SURA) <sup>2</sup>. As a result of this project, we have enabled more than 800 active projects on the system representing 619 individual researchers conducting large-scale computational science. This resource has facilitated researchers across the nation from fields of science ranging from computational physics and chemistry to linguistics and social science. The Longhorn team worked in collaboration with Dell Computers to architect a commodity based system that could be easily replicated at other universities on a multitude of scales. As a result of this funding, we have trained hundreds of people at institutions across the nation with a targeted effort to conduct training at Minority Serving Institutions.

I am also tasked with setting research direction and maintaining a visualization laboratory that serves the University of Texas at Austin population. This 2900 square foot laboratory is home to one of the largest tiled displays in the world, with a peak count of 328 million pixels. In this laboratory, we research and develop tools and interaction mechanisms for

<sup>2</sup> Gaither, K. (PI), "Enabling Transformational Science and Engineering Through Integrated Collaborative Visualization and Data Analysis for the National User Community," NSF XD VIS (\$7,000,000) August 2009 – July 2012.

next generation visualization environments that can be replicated at a variety of scales across a multitude of institutions. We also designed and constructed a large-format touch table that has 32 point touch capability at 5mm resolution. This touch table behaves much like an oversized iPad providing a natural mechanism for learning and rapidly testing new research concepts. Additionally, the visualization laboratory has had more than 18,000 people come through the doors, many of which are K-12 students. While we work diligently to provide a production visualization laboratory to the UT Austin constituency, we also research and develop displays and interaction mechanisms for visualizing next generation science. To this end, we recently submitted a proposal to research a new paradigm for data exploration through the seamless integration of multiple spatially aware visualization systems that form a visualization ecosystem. Recent advances in human-centered computing have introduced computing interfaces that enable the user to interact with, and manipulate compute devices and data displays in a more intuitive manner. Specifically, recent trends in mobile computing, cloud computing, and ubiquitous computing have simplified human-computer interactions with everyday devices. The trends and advancements in these areas have laid the foundation for a new abstraction that will bridge a gap in human-computer interaction. This abstraction, shown in Figure 2, will provide a seamless environment in which individuals can navigate data unimpeded by the physical constraints and boundaries set by compute devices and displays, and will provide a reactive environment that evolves with user defined interactions.

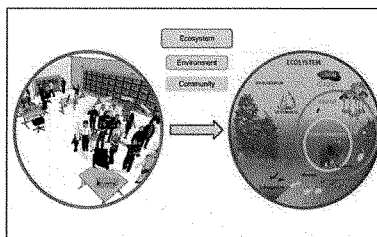


Figure 2: This next generation visualization laboratory is an analog of the biological ecosystem that seeks to develop an interactive, reflective, and reactive computing environment for visualization.

The funding for these projects and others has enabled me to have a national impact by developing leading programs in visualization and training for future computational scientists. The investment in computational science in general, and high end computing specifically, have provided much needed resources for me and for a large number of researchers working on national open science problems. These resources and technologies require a significant investment. Without them, we as researchers would be bound by investments at the institutional scale, significantly inhibiting our ability to fully exploit intellectual meritorious research at full scale.

Science can only advance with better, more capable tools – be they software, hardware or some blend therein. Building on prior knowledge and capabilities allows us to leverage the innovations of researchers that have come before us. Without new scientific capabilities, we hamstring research and inhibit our ability to move forward. We are a

country of innovators and this innovation must be fostered with significant investment and patience. Building on the work of others fundamentally depends on us having access to new capabilities that prior researchers did not have. The NITRD program gives us those resources and funding for resources at a scale that individual institutions would not be able to afford otherwise.

#### **Significant Research Directions NITRD Should be Pursuing**

First let me commend the efforts to create national programs with increasing focus on data. There are many fields of science that depend on our ability to quickly process vast amounts of data. Currently, data growth rates far outstrip our ability to process and analyze it. However, increasing the focus on data intensive computing should not be done to the exclusion of funding research and development in modeling and simulation. It is imperative that we, as a national IT strategy, strive to build a balanced portfolio of funding opportunities that focus on all aspects of next generation science.

We can see evidence of a shift in the nation's High End Computing strategy. The National Science Foundation is now funding one or two high-end resources every other year versus the one or two a year they funded in the past. This decrease in HEC funding is not limited to the resources themselves, but extends to many of the underlying scientific applications and crucial software tools as well. This dip in resource provisioning is at odds with the increased need for high end computing technologies in open science research.

Additionally, there has always been a lack of persistent funding for visualization. It is generally agreed that visualization is a powerful means of synthesizing data, but many equate visualization with vision and take it for granted. However, the transformation from data to visual imagery is rooted in scientific principles that include concepts in human perception, numerical linear algebra and cognition. Blending these concepts in a reproducible, concise visual context allows us to create meaningful information from vast amounts of data. While it is generally recognized that visualization is a crucial part of the science pipeline today, it will only be more crucial in the big data era. We need students and researchers well versed in numerical algorithms, data mining, statistics, and computer science, but there is nothing as efficient as a great visualization to communicate science.

As complexity increases, so does the need for visualizations that act as both a communications mechanism and a teaching tool. Persistent funding is needed for visualization – including scientific visualization, information visualization and visual analytics. At TACC, we are committed to researching and developing visualization tools and providing visualization resources to both local and national user communities. At present, there is very little funding for this relative to the need in the open science community.

#### **Ensuring a Persistent Pipeline to Meet the Nation's IT Needs**

I graduated from high school in one of the poorest states in the nation at a time when young women were not encouraged to pursue higher education, let alone major in computer science. Fortunately, I was encouraged by my family to make some strategic decisions regarding career choices, and I have had the opportunity to work with a number

of mentors in all aspects of computational science. I have been paid by federally funded computational research dollars since I was roughly 24 years old. I am a by-product of long-term federal funding for basic and applied research. Without this funding, I would not have had the opportunities to participate in many of the interdisciplinary projects that focus on solving some of society's most challenging issues – hurricane prediction, imaging the human body at the subcellular level, and designing safer, more fuel efficient vehicles to name a few. There is no substitute for immersing students in all aspects of computational research throughout their educational process. This immersion, however, requires persistent commitments from funding agencies and educators alike. We need opportunities to educate students in interdisciplinary research and provide invaluable hands-on experience working with teams of researchers. Funding for research programs and graduate students to work on these programs is crucial to making fundamental advances. There is no substitute for more research funding. However, in national IT at the leading edge, we also need a curriculum change to carve out a home for students to thrive. The overwhelming business need in the dot.com era shifted the attention to focus specifically on those needs, a necessary shift at that time. We are missing a thriving focus on research and development that is not driven by quarterly profit bottom line. There needs to be much more investment in curriculum development for people to work on the science and data intensive applications for large-scale problems. To put it succinctly, there must be curriculum, there must be funding, and there must be exciting opportunities for our students to stay in the field.

#### **Summary of Testimony**

I would like to reiterate my appreciation for allowing me to speak to you today about the impact that the NITRD program has had in my research and subsequently for the general public. In closing, I would like to summarize the key points I have spoken about today:

1. **Make significant continued investments in the NITRD program.** As a taxpayer, I recognize that these are tight economic times. However, as a researcher I know that investments in research will keep us at the forefront of innovation. We must not shortchange our commitment and vision to continue the successes of those that have come before us.
2. **Maintain a balanced portfolio of NITRD funding opportunities for researchers in computational science.** We must find a way to fund additional investments, not to the exclusion of existing funding streams. It is a combination of efforts that is most likely to be fruitful.
3. **Provide exciting opportunities to entice students to stay in computational science.** We must deal head on with the brain drain that our universities are experiencing in undergraduate and post-graduate education. While, there is no magic bullet that will solve this problem, it seems clear that a new approach is warranted. This new approach requires an investment in both curriculum development and student research to provide exciting opportunities for future generations of scientists.

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[1] K. P. Gaither, H. Childs, K. Schulz, C. Harrison, B. Barth, D. Donzis, and P. Yeung. Using Visualization and Data Analysis to Understand Critical Structures

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in Massive Time Varying Turbulent Flow Simulations. *IEEE Computer Graphics and Applications*, 32(4):34-45, 2012.

Chairman BUCSHON. Thank you, Dr. Gaither.  
I now recognize Dr. McKinley for five minutes to present her testimony.

**TESTIMONY OF DR. KATHRYN MCKINLEY,  
PRINCIPAL RESEARCHER, MICROSOFT**

Dr. MCKINLEY. Chairman Bucshon, Ranking Member Lipinski, and Members of the Subcommittee, thank you for inviting Microsoft to testify and your attention to how IT innovation helps the Nation create jobs and grow our economy. I am Kathryn McKinley. My experiences with the National Science Foundation, the National Academies, DOE, and DARPA, and as an Endowed Professor at the University of Texas at Austin, and my current role as Principal Researcher at Microsoft inform my testimony.

First, I would like to point out that an interconnected IT research ecosystem has made the United States the world's leading economy with the best defense capabilities. The results of IT research include new billion-dollar industries that create jobs and make us safer, healthier, more efficient, and delight us.

One example is the Microsoft Xbox 360 Kinect. With Kinect, your voice and your body are the game controller. Kinect combines decades of research at Microsoft and elsewhere on artificial intelligence, graphics, motion detection, and voice recognition. New technologies inspire more innovation, and now, Kinect is advancing learning, health, and retail. Kinect exists because Microsoft's business strategy is to make long-term investments and bets. Twenty years of investment in Microsoft Research has made Microsoft Research the largest and most successful computing research organization in the world. Yet Microsoft thrives as a part of a larger research ecosystem partnering with government, industry, and academia.

Key IT research areas for our Nation and for NITRD include big data, privacy, and building trustworthy systems. A particularly important research challenge that I work on is that your computer is no longer getting faster every year. In the past, doubling of performance every two years drove new computing capabilities and accelerated innovation in IT. Unfortunately, current technology is up against some fundamental limits, and no new technologies are ready to overcome them.

The technical challenges are compounded by global competition. Substantial investments in Asia and Europe have increased their contributions to the research ecosystem and their participation in the global IT economy. While the United States still enjoys an advantage, the gap is narrowing. Significant research investments in areas such as semiconductors, materials, architecture, and programming systems are needed. If the overall rate of innovation slows, it will be easier for other countries to close the gap and the United States will lose its economic and national security advantages.

Let us talk about education. Technology is and will infuse all aspects of life in the 21st century. People who understand IT will flourish in the global knowledge economy. The U.S. computing workforce demands are outpacing its supplies. Forty thousand people earned a computing Bachelor's degree last year, but that is not



enough because we are projected to have 120,000 openings for jobs that require a computer science degree. The United States, including federal agencies, must strengthen computing education at all levels, including K through 12, to fill these jobs.

A particular challenge in computing is the limited participation of women, Hispanics, and African-Americans. My community, through efforts such as the Computing Research Association, where I am a Board Member and a Committee Co-Chair, has programs that are proven to increase the success of women and minorities by mentoring Master's and Ph.D. graduate students and giving undergraduates research experiences. But we need more success stories. The United States simply cannot afford to fail to capitalize on the creativity of 70 percent of its population if it wants to remain globally competitive. The IT knowledge economy depends on the flow of the best people and ideas between academia, government, and industry.

I would like to finish with a little of my own personal story. I did not go to college intending to become a researcher or even a computer scientist. I came from a family of lawyers. I took a computer science course and then Professor Don Johnson at Rice University hired me for a summer research project. That experience opened my eyes to the excitement of solving problems where no one knows the answers. And that could be my job. But tight integration of research and education makes the U.S. research universities the best in the world.

I thank you for this opportunity to testify and your Committee's long-standing support for IT research and innovation. I would be pleased to answer questions.

[The prepared statement of Dr. McKinley follows:]

**Written Testimony of  
Dr. Kathryn S. McKinley  
Principal Researcher, Microsoft Research**

**Before the  
Subcommittee on Research, Committee on Science, Space, and Technology  
U.S. House of Representatives**

**Hearing on  
“Applications for Information Technology Research and Development”**

**February 14, 2013**

Chairman, Ranking Member, and Members of the Subcommittee, my name is Kathryn S. McKinley, and I am a Principal Researcher at Microsoft. Thank you for the opportunity to share perspectives on information technology research in the U.S., including in universities and at companies. I appreciate the time and attention the Committee has devoted to this topic, and I commend you for advancing the dialogue on innovation and competitiveness in information technology.

Microsoft deeply believes that investment in research and education lay the groundwork for advances that benefit society and enhance the competitiveness of U.S. companies, U.S. security, and the lives of individuals. In my testimony, I will describe

- Key elements of the information technology research and development (R&D) ecosystem.
- Microsoft Research and an illustration of how innovative new products build on a wide range of research activities.
- The two core pillars of NITRD – investment in discovery and investment in people – and examples of important research areas for NITRD going forward.

A brief summary of the key points covered in my testimony is provided at the end of this document.

My testimony today is informed by my experiences in academia and industry. I am a Principal Researcher at Microsoft Research and an Endowed Professor of Computer Science at the University of Texas at Austin, and previously was a Professor at the University of Massachusetts, Amherst. My research interests include programming language implementation, compilers, memory management, runtime systems, security, reliability, and computer architecture. I particularly focus on practical research that results in systems that substantially improve the performance, correctness, security, and, most recently, power of applications. The National Science Foundation (NSF), IBM, DARPA, Microsoft, Google, CISCO, and Intel all supported my research in academia.

Today, in addition to my work at Microsoft and on NSF, IBM, DARPA, Microsoft, Google, CISCO, and Intel research community activities, I am a member of the Board of the Computing Research Association (CRA), co-chair of the CRA's Committee on the Status of Women in Computing Research (CRA-W), and a member of the Defense Advanced Research Projects Agency's Information Science and Technology Study Group (ISAT).

### **The IT R&D Ecosystem**

The commercial information technology (IT) industry is a well-known and appreciated success story of American innovation and leadership. American ingenuity turned advances in IT into an incredible driver for global competitiveness, military preparedness, and economic growth. Today, IT contributes about 5% to overall U.S. GDP, according to the Bureau of Economic Analysis. Yet the success was not solely the outcome of visionary and very hard-working people at companies across the U.S., such as Microsoft. Instead, the success and impact of IT is the result of a tightly interconnected ecosystem of people, ideas, projects, and resources from government, academia, and industry.

The nature of this complex partnership is illustrated in the 2012 report *Continuing Innovation in Information Technology*.<sup>1</sup> This report illustrates how fundamental research in IT, conducted in industry and universities over decades, and supported by Federal agencies, has and continues to lead to the introduction of entirely new product categories that ultimately have become the basis of new billion-dollar industries. In all these cases, there is a complex interweaving of fundamental research and focused development that subsequently create opportunities for new research, new products, and new markets. Innovations in academia continue to drive breakthroughs in industry, and vice versa, fertilized with ideas, technologies, and people transitioning among disciplines and institutions.

Without research agencies and universities to focus research on the ever-shifting frontiers of multiple computing sub-disciplines, to explore connections across disciplines, and to expose and train each generation of students to create the next set of innovations, companies will not have the reservoir of ideas and talent to maintain the U.S. lead in today's IT sector and to build the next set of multi-billion dollar job-creating industries.

### **Microsoft Research**

Microsoft is a direct beneficiary of, and wholly committed to, its role in the innovation ecosystem described above. This commitment requires Microsoft to make significant investments in all elements of this ecosystem. Across the company, more than \$9 billion a year is directed toward research and development (R&D) with the vast majority of those funds supporting development activities focused on specific products. A critical element, although small in relative terms, of our overall R&D investment is in more fundamental explorations at Microsoft Research (MSR). Founded in 1991, MSR is now the largest and highest quality industrial computing research organization in the world, with over 800 Ph.D.s working in more than 55 research areas. MSR is

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<sup>1</sup> *Continuing Innovation in Information Technology*; Committee on Depicting Innovation in Information Technology; Computer Science and Telecommunications Board; Division on Engineering and Physical Sciences; National Research Council. [http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB\\_045476](http://sites.nationalacademies.org/CSTB/CurrentProjects/CSTB_045476).

dedicated to advancing the state of the art in computing, often in collaboration with academic researchers (graduate students, undergraduate students, and professors) and government agencies, and to creating new technologies for Microsoft's products and services. This organization and these people allow Microsoft to respond more rapidly to changing markets and emerging technologies and to provide a reservoir of technology, expertise, and people that can be quickly brought to bear to respond to and create new technologies, new business models, and new markets.

While MSR activities are distinct from the short-term development activities conducted at Microsoft and other companies, distinctions such as "basic" versus "applied" do not really apply to computing research. In fact, computing research is an evolving blend of invention, discovery, and engineering. MSR researchers collaborate with leading academic, government, and industry colleagues and often move in and out of universities and Microsoft business groups as their activities shift in focus between research, applications of that research, and technology transfer and implementation.

A recent example of how research comes to fruition in Microsoft is Microsoft's Kinect product, which links to an Xbox system and allows you to control your Xbox games and other functions with your body and voice. The most innovative achievements of Kinect are the creation of a system that recognizes people and their voices in a variety of environments; that tracks and responds to their body motions in real time; and that this system can be produced in bulk. The technology builds on decades of blue-sky and disruptive research, conducted both in academia and in MSR, in a range of areas, including machine learning, image processing, audio processing, and natural language processing. Furthermore, this technology is now inspiring new directions in cross-disciplinary research on virtual and augmented reality, secure video presence, health monitoring, and education.

The impact of Kinect is just one example of the connections and synergies between industry and academia that are discussed in the *Continuing Innovation in Information Technology* report and that illustrates how information technology shifts and evolves from research to products back to research. By providing a flexible and affordable system by which visual and voice feeds can be processed and used by a computer, Kinect is already transforming a variety of academic research projects and applications in robotics, human-computer interaction, online education, and more. In addition, the advances originally targeted at the gaming and entertainment business are having multiplier effects outside the IT sector as the technology is investigated for deployment in retail (virtual car tours)<sup>2</sup> and for healthcare applications (such as autism or post-stroke physical therapy).<sup>3</sup>

#### **NITRD**

As a nation, we can be proud of the achievements and innovations due to the IT R&D ecosystem to date, including those spurred by the Federal government under NITRD, but U.S. global leadership, the future health of the economy and national security depend on government investment in research to accelerate technological innovation, address societal challenges, and

<sup>2</sup> More information about how the Kinect is being used in other commercial sectors is available at <http://www.microsoft.com/en-us/kinectforwindows/>.

<sup>3</sup> More information about how the Kinect is being used in healthcare, education, the arts, and other applications is available at <http://www.xbox.com/en-US/Kinect/Kinect-Effect>.

train a globally competitive workforce. The activities and investments of the past lay the groundwork on which we can build going forward. Support, oversight, and reauthorization of NITRD is a critical step toward providing Federal research agencies with the resources and guidance they need to stimulate our innovation ecosystem.

### Investing in Research

The potential results and impact of research are often unknown when the research is started. The value and payoff of a sustained and healthy investment in research is often realized well after the initial investment and research. Today, the U.S. is reaping the benefits in our quality of life, the global competitiveness of our companies, and our national security that build on past investments, as is highlighted in the *Continuing Innovation in Information Technology* report.

Looking ahead, NITRD investments to advance computing capabilities are required in a range of areas to generate the next generation of technological innovations, as has been discussed in reports and past testimony<sup>4</sup>:

- **Data volumes are growing exponentially.** Health, cameras, video, motion, and other sensors can produce and stream an enormous volume of electronic information. “Big data” and “streaming data” pose great challenges, including how to collect, manage, access, search, analyze, and act on this data efficiently in bulk and in real time. Solutions require substantial innovations in software, networking, and hardware (from embedded to mobile to cloud), and have the potential to revolutionize society with applications ranging from personalized education, continuous health monitoring, personal assistants, enhanced social networks, robotics, smart buildings, and efficient transportation.
- **Computing systems must be trustworthy and privacy preserving.** As more of government, the economy, and individuals depend on information technology, we must create and combine technical, social science, and policy solutions to meet the wide range of risk and trust environments.
- **Technologies driving computer hardware capabilities are reaching fundamental limits.** Over the past three decades, we have enjoyed exponential improvements in computing hardware performance due to substantial innovations in materials, hardware, and software, and because the hardware/software interfaces did not change much, the improvements created a virtuous cycle of innovation on both sides of the interface. However, today, on the hardware side, the physical constraints on power, wire delay, and feature sizes are forcing single-processor performance to plateau. These constraints require substantial research and

<sup>4</sup> Relevant reports and testimony include:

- *The Future of Computing Performance: Game Over or Next Level?*, Samuel H. Fuller and Lynette I. Millett, Editors, National Research Council Committee on Sustaining Growth in Computing Performance, National Academies Press, 2010. [http://www.nap.edu/catalog.php?record\\_id=12980](http://www.nap.edu/catalog.php?record_id=12980)
- Two reports entitled *Designing a Digital Future: Federally Funded Research and Development Networking and Information Technology*, President’s Council of Advisors on Science and Technology, 2010 and 2013. <http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd-report-2010.pdf> and <http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd2013.pdf>
- Testimony by Dr. Peter Lee, Microsoft Research, before the Senate Committee on Commerce, Science and Transportation on September, 2012.

innovations up and down the hardware/software stack to provide continued growth in computing capabilities.

As examples of how computing research will connect with national and business priorities going forward, I will discuss at greater length two key research areas: (1) increasing hardware capabilities as traditional hardware reaches its limits, and (2) managing the energy usage of information technology in a wide range of settings.

In the first area, the National Academies recently completed a study on *The New Global Ecosystem in Advanced Computing: Implications for U.S. Competitiveness and National Security*<sup>5</sup> that addresses these research needs and consequences if they go unaddressed. (I am an author of this report.) Over the past 35 years, the IT industry and all those who use IT products, have benefited greatly from the steady and dramatic (exponential) increases in microprocessor performance.

Every two years until about 2005, performance of computers doubled, which underpinned and drove rapid, dramatic, and systemic increases in the speed of software and increases in new software capabilities. However since 2005, the advances in performance have plateaued due to fundamental limits of physics and silicon materials. No new technology is waiting to replace this technology. One current solution industry is pursuing is parallel computing (more processors, rather than faster processors), but this solution presents substantial hardware and software challenges, since, in particular, most software is not parallel. There are many research ideas on how to continue the scaling of computing performance, but more than ever before this research depends on achieving greater levels of hardware/software integration, innovation, and co-design than ever before. This incredibly challenging, exciting, and important problem is one that is arguably underfunded today.

However, if the performance engine of the virtuous cycle of hardware and software capabilities goes dry, the gap between our nation's capabilities and other nations' will narrow substantially. Significant investment in hardware and coordinating programming software system capabilities are needed by government, academia, and industry to establish a new virtuous cycle of hardware/software innovation in the post-Moore's Law era.

Global competition is compounding the technical challenges. Whereas until recently, the vast majority of computing research was centered in the U.S, substantial investments in Asia and Europe are spurring global IT innovation. For example, studies of papers published, patents, and collaborations occurring internationally show that in four key computing fields – semiconductor devices and circuits, architecture, applications, and programming systems – the distribution of research and innovation is shifting. For example, Figure 1 shows the international collaboration network on scientific publications at the most prestigious and influential scholarly publication venues in these areas, reproduced from *The New Global Ecosystem in Advanced Computing*.<sup>5</sup> The U.S. is still the leader in these areas, but it is no longer the sole locus and driver of innovation, countries such as China, Japan, Korea, Taiwan, Great Britain, and Germany have increased both

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<sup>5</sup> *The New Global Ecosystem in Advanced Computing: Implications for U.S. Competitiveness and National Security*; Committee on Global Approaches to Advanced Computing; Board on Global Science and Technology; Policy and Global Affairs; National Research Council. [http://www.nap.edu/catalog.php?record\\_id=13472](http://www.nap.edu/catalog.php?record_id=13472).

their contributions to the research ecosystem and their ability to convert research into technological advancements. While the U.S. enjoys an edge, the gap is narrowing.

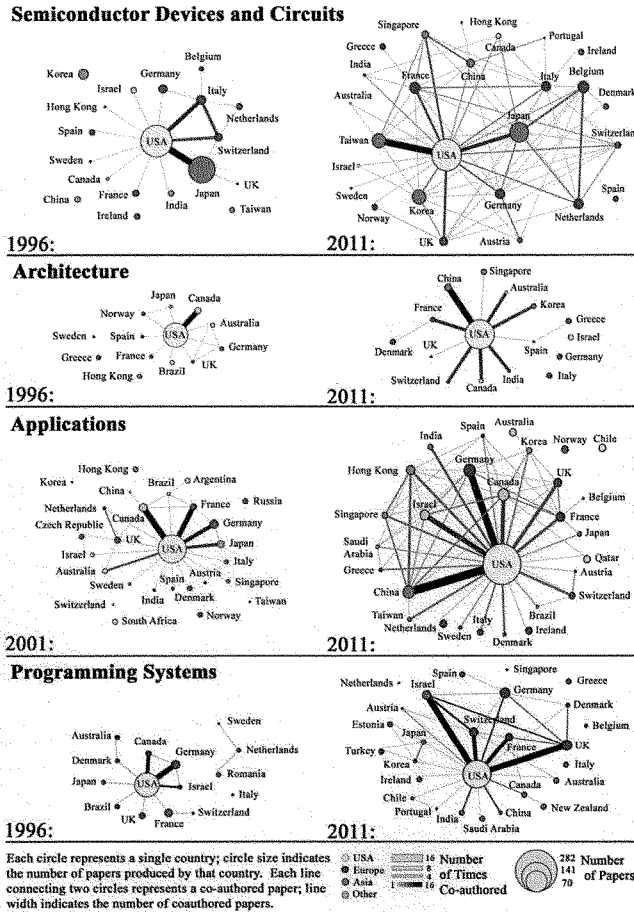


FIGURE 2-1 International conference collaboration networks. Data compiled from the following conferences: ASPLOS, HPCA, ISCA and MICRO (architecture); ECOOP, OOPSLA, PLDI, POPL, and PPOPP (programming systems); SC, SIGGRAPH, VLDB, and WWW (applications); and IEDM and ISSCC (semiconductor devices and circuits). Collaboration maps were generated using the Science of Science (Sci2) Tool available at <http://sci2.cns.iu.edu>.

Figure 1. From *The New Global Ecosystem in Advanced Computing: Implications for U.S. Competitiveness and National Security*; Committee on Global Approaches to Advanced Computing; Board on Global Science and Technology; Policy and Global Affairs; National Research Council. [http://www.nap.edu/catalog.php?record\\_id=13472](http://www.nap.edu/catalog.php?record_id=13472).

This change in circumstances has implications for the U.S. both in its internationally-leading IT sector and its national defense strategies. Both our companies and our defense technologies have benefitted from having first access to steadily improving overall IT functionality, but as the innovation networks and supply chains become more global, the U.S. must prepare and adapt. In particular, if the rate of innovation slows, closing the gap becomes easier and the U.S. will lose its competitive advantage. From a research perspective, as the report notes, “major innovations in semiconductor processes, computer architecture, and parallel programming tools and techniques are all needed if we are to continue to deliver ever-greater application performance.” This research will build on sustained past investment in these areas supported by NITRD and requires intellectual and practical contributions from universities, government, and companies.

In the second area, the expanding deployment of computing devices at all sizes and scales (from mobile devices in every pocket to massive data centers that require their own power plants) has highlighted the challenge of efficiently powering microprocessors to perform a vast array of different tasks. Also, the technological shifts described above mean that IT designers face tradeoffs between performance and power in everything from checking a phone’s location via GPS to running searches on thousands of servers in data centers. Research on power and performance tradeoffs will have implications for hardware, architecture, and application design going forward with a first order effect on mobile user experiences and the economics of cloud services. Furthermore, advances in both have direct effects on enhancing the safety and effectiveness of the military, ranging from improving military intelligence and planning, to helping soldiers during combat.

The above list and examples are not meant to imply that NITRD is not working on these and other important areas. To the contrary in the past several years, we have seen significant interagency collaboration on research targeted at major challenges and opportunities. Two recent examples are the initiatives in robotics and big data. Similar to the examples described above, they are simultaneously areas for cutting-edge fundamental research on hard problems that will occur at universities, industry, and government laboratories, and also the focus of development and deployment activities at corporations and agencies.

**Investing in People: *The Nation’s computing workforce demands are outpacing its supply.***

To create the next generation of highly skilled IT workers requires improving the nation’s K-12 education in computing to feed our universities and requires broadening the IT talent pool to include the missing 70%, women and under-represented minorities.

As information technology permeates more aspects of our day-to-day lives and becomes a critical element of sectors from manufacturing to healthcare, from retail to education, U.S. industry and government will be searching for people with the core knowledge and creativity to reinvent how we do business and keep American companies at the forefront of the global economy. Careers in technology, engineering, science, and mathematics will be growing, especially those in computing. Based on Bureau of Labor Statistics data, jobs in computing occupations are expected to account for 62 percent of the projected annual growth of newly created science, technology, engineering, and mathematics (STEM) job openings from 2010 to 2020.



At Microsoft, we are very aware of this issue today. The success of Microsoft is strongly dependent on the capabilities of our employees. We aggressively seek out talented people who will help build our company into one that is successful in improving our current products and creating new ones as we participate in the rapid change that characterizes our innovation-based economy. Yet in January 2013, Microsoft had more than 3,400 unfilled research and engineering positions in the United States, a 35 percent increase in our number of unfilled positions for these types of positions compared to a year ago. Microsoft has proposed a “National Talent Strategy” that couples responding to our short-term workforce challenges with long-term investments in improving our STEM education system, including computing education in high school, and we are working with other companies, organizations, and governments on these challenges.<sup>6</sup>

Ensuring that students have the opportunity to explore careers in computing and the support to succeed in those careers requires contributions from the government, industry, and education communities and improvements at all levels of the educational pipeline. For example, the National Science Foundation’s Computing Education for the 21st Century (CE21)<sup>7</sup> program has helped create innovative new courses for high school students to inform and inspire more participation in computing. Unfortunately, in 2009 only 5% of high schools offered the AP Computer Science class (2,100 out of 42,000). Furthermore, only nine states allow computer science courses to count toward “core” math and science high school graduation requirements. More information about the opportunities and policy challenges is available from the Computing in the Core coalition (<http://www.computinginthecore.org/>), of which Microsoft is a founding member.

A particular element of the challenge relates to the relatively limited participation of women and Hispanic and Black minorities in computing. The failure to capitalize on the creativity of these groups is a huge opportunity cost to our nation’s leadership in technical innovation. The business case for a diverse work force is compelling. A 2007 study from the National Center for Women in IT shows that IT patents issued to mixed gender teams are cited 26% to 42% more than similar IT patents by all men or all women teams.<sup>8</sup> In 2009, Herring found that companies with the highest levels of racial diversity had 15 times more sales revenues than those with lower diversity.<sup>9</sup>

In 2011, white men were 31% of the U.S. population and yet received 61% of the bachelor degrees in computer science (see Figure 2). Looking specifically at the research workforce in 2011, out of 1782 Ph.D.s in 2011, women earned only 345 Ph.D.s, less than 20%.

<sup>6</sup> The Microsoft National Talent Strategy is available at <http://www.microsoft.com/en-us/news/download/presskits/citizenship/MSNTS.pdf>.

<sup>7</sup> The National Science Foundation’s Computing Education for the 21st Century (CE21) program focuses on generating knowledge and activities related to computing education with the goal of building a robust computing research community, a computationally competent 21st century workforce, and a computationally empowered citizenry. The program is described at [http://nsf.gov/funding/pgm\\_summ.jsp?pims\\_id=503582](http://nsf.gov/funding/pgm_summ.jsp?pims_id=503582).

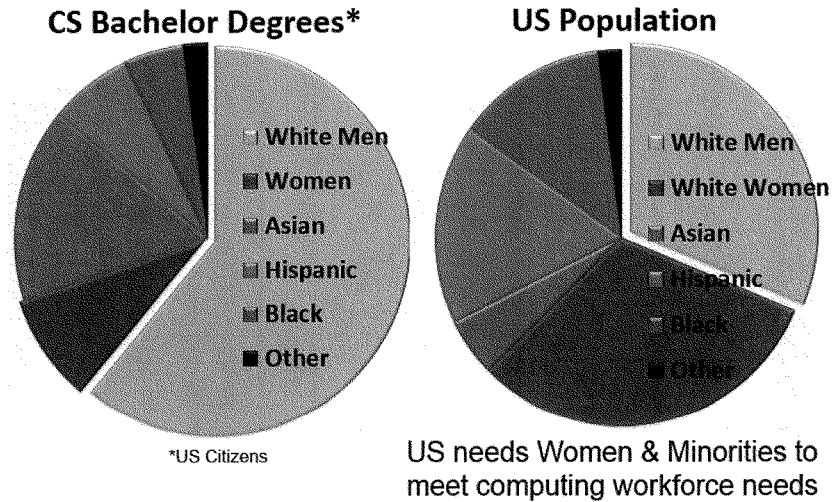
<sup>8</sup> *Who invents IT? An Analysis of Women’s Participation in Information Technology Patenting*, C. Ashcraft and A. Breitzman, Technical report, NCWIT, March 2007.

<sup>9</sup> *Does Diversity Pay? Race, Gender and the Business Case for Diversity*, C. Herring, *American Sociological Review*, 74(2):208–224, 2009.

***The U.S. simply cannot afford to stand by while 70% of its population does not participate in the computing ecosystem of the "knowledge economy" and remain globally competitive.***

After I joined Microsoft Research in 2011 and with the enthusiastic support of Microsoft, I became the co-chair of the Computing Research Association (CRA) Committee on the Status of Women in Computing Research (CRA-W), which is working to fill the computing workforce needs with programs that accelerate innovation by improving the participation and success of undergraduates, graduate students, and Ph.D. women and minorities in computing research. Furthermore, CRA-W recently helped establish the CRA Center for Evaluation of the Computing Research Pipeline (CERP) to evaluate how well intervention programs work and what leads students to pursue computing research careers.

Figure 1: Computing Demographics: The Missing 70% <sup>10</sup>



<sup>10</sup> Sources for figure: Computing Research Association, Taulbee Survey 2010-2011, available at <http://www.cra.org/resources/taulbee/> (providing voluntary responses from Ph.D.-granting universities on new enrollments and degrees awarded in their undergraduate, CS/CE programs. U.S. Census Data 2011, available at <http://quickfacts.census.gov/qfd/states/00000.html>

Below are two examples of ongoing CRA-W programs that expand the research workforce, as shown by comparisons of program participants with the national pool of computing students.

- *Support for Women in Graduate School:* The CRA-W Grad Cohort is a two day mentoring workshop that brings computing graduate students together with successful senior women researchers, who serve as role models, give practical advice and information on navigating graduate school, and provide personal insights on the challenges and rewards of their own careers. The workshop provides group and individual mentoring, networking, and peer support for women master's and Ph.D. students—this experience is something their home institutions, most with very few women, do not provide. Between 2004 and 2012, 2089 graduate students participated in a Grad Cohort and 245 attended in 2012, impacting an enormous fraction of the women who subsequently go on to earn Ph.D.s. Surveys comparing Grad Cohort participants with nonparticipants in a national survey, showed participants were twice as likely to publish and over three times more likely to be a first author on a research publication. Ph.D. students who have a broader technical network and publish are more competitive in the job market.
- *Undergraduates and Research Experiences:* Each year, CRA-W and the CRA Coalition to Diversify Computing (CDC) match between 50 and 100 women and minority undergraduate students with faculty across the U.S. based on mutual research interests. Students, many whose home institutions are without computing research programs, spend an intense 10 weeks working closely with a faculty researcher, typically at another university. Faculty serve as role models and research mentors. The student and faculty agree on a research project, report on their progress monthly, publish a web page, and issue a final research report. Some of these reports turn into peer-reviewed research publications. These programs inform and encourage women and minorities to pursue computing research careers, and enhance and expand their experiences beyond the classroom. Undergraduate program participants are significantly more likely to apply (51% vs. 23%) and enroll (39% to 19%) in graduate school in computing than nonparticipants, and, if at graduate school, to enroll in a Ph.D. program (81% vs. 18%).

These activities are a community effort, supported by the National Science Foundation, by Microsoft, by other companies, by universities, and by volunteer participants throughout the community. They are complemented by other activities targeted at women, at minorities, and at the student population in general. For example, at Microsoft, we bring over 1,800 student interns to Redmond each year, with over 300 in Microsoft Research. The MSR interns participate in cutting-edge research and learn about how advances fit into the context of a company that must continuously provide innovative products to thrive. This experience helps prepare students for a variety of career paths – as professors, as entrepreneurs, as industry researchers, and some as Microsoft employees.

Improving students' opportunities to explore and succeed in computing careers and research careers, including the participation of women and minorities, is critical to assuring our nation's security and building an innovative and growing economy. Federal agencies should continue to support efforts to strengthen computing education at all levels. In addition, general Federal STEM programs must recognize that computer science is a critical component of their purview due to its largest predicted workforce gap, and thus articulate its particular needs for curriculum reform and clearly support its inclusion through their solicitations, outreach, and review criteria.

**Conclusion**

In conclusion, I want to emphasize that the U.S. has a strong and effective innovation system in information technology in which Federal agencies, companies, and universities all play major roles. This ecosystem ensures new knowledge is created and deployed for the sake of the nation's economic competitiveness, national security, and society's well-being, and that our education system produces the next generation of computing workers and leaders that are required to sustain and accelerate innovation in the information technology ecosystem.

Finally, let me thank you for this committee's longstanding support for IT research, discovery, and innovation. I would be pleased to answer any questions you might have.

### Summary of Testimony

- Past investment in computing research has spawned multiple new billion-dollar information technology (IT) industries that have significant positive impact on the U.S. economy as well as enabling innovation in multiple sectors, such as manufacturing, healthcare, energy, entertainment, education, and retail.
- Government, universities, and industry each play a critical role in advancing IT innovation and discovery. In particular, Federal investment, through the NITRD program is vital in providing sustained support of research in existing and emerging computing areas and in enabling the training and flow of people and ideas throughout the IT R&D ecosystem.
- Research at Microsoft is a critical investment for the company and contributes to the creation of new products, such as Kinect, that build on, accelerate, and inspire advancements in multiple areas of computing. Furthermore, Microsoft Research thrives within the larger computing research community, which provides ideas and a pool of talented researchers that Microsoft hires and with whom Microsoft researchers collaborate.
- Looking ahead, there are a number of key investments to be made in computing research, and NITRD in particular. Areas with economic, societal, and security impacts include fundamental multi-disciplinary computing challenges in areas such as big data and robotics, as well as the computing advances needed to tackle national challenges in energy, education, health, and defense.
  - In particular, a major research challenge and opportunity is due to the plateauing of single-processor performance and shifts in global innovation networks with implications for the U.S. economy and defense.
- The 21st century will be a technology-infused world, where our innovators, employees, and citizens will need computing knowledge and skills. We must continue to strengthen students' ability to access rigorous and engaging computing education at all levels (K-12, undergraduate, and graduate) and include computer science in broader science, technology, engineering, and mathematics education efforts.
  - In particular, work must continue on ensuring that the full range of our population, including women and under-represented minorities, have the opportunity to explore and succeed in computing and computing research careers.
- Support, oversight, and reauthorization of NITRD is an important step toward providing Federal research agencies with the resources and guidance they need to contribute to our innovation ecosystem.

Chairman BUCSHON. Thank you, Dr. McKinley.  
I now recognize Dr. Lazowska to present his testimony.

**TESTIMONY OF DR. ED LAZOWSKA,  
BILL AND MELINDA GATES CHAIR  
IN COMPUTER SCIENCE AND ENGINEERING,  
UNIVERSITY OF WASHINGTON**

Dr. LAZOWSKA. Well, I, too, would like to thank Chairman Bucshon, Ranking Member Lipinski, and the Members of the Subcommittee for the opportunity to speak today.

My name is Ed Lazowska. I am a longtime faculty member at the University of Washington. I have been a member or Chair of many federal IT Advisory Committees. Most recently, I was Co-Chair of the Working Group of the President's Council of Advisors on Science and Technology that conducted a review of the overall NITRD program in 2010.

What that review found—and you have heard about this from the other two witnesses—is that the research ecosystem supported by the NITRD program has been the primary factor in America's world leadership in information technology. And if we are going to remain competitive in this increasingly competitive world, there is honestly no field in which it is more important to maintain our leadership than information technology.

So what I want to do today is focus on one aspect of my written testimony, and that is the unique and essential role of the relatively modest federal investment in IT R&D. The National Research Council over many years, going back to 1995, a report I participated in, has constructed a series of diagrams that attempt to explain how this works, how this ecosystem fits together. I want to say for Mr. Lipinski, who has seen previous versions of this diagram, that this one is new and improved, just out a few months ago. And in fact, the individual who produced this is Peter Lee, who is the Vice President for Microsoft Research in the United States.

This diagram is a timeline that runs from bottom to top and it tracks the growth of eight major sectors of the IT industry, broadband and mobile, microprocessors, personal computing, and so on. They are labeled near the top. There are three lines for each sector. Let me just take a second and explain this. The red line shows research performed in universities mostly with NITRD funding. The blue line in the middle shows when industry R&D organizations were working in the same sector largely with private-sector funding. The dotted black line shows when the first product was introduced. When that line becomes green, it became a billion-dollar market sector. When the green line gets thicker, it becomes a \$10 billion market sector. The small diagonal arrows you can barely see are the flow of specific key people and ideas between academia and industry and between the sectors. It looks like someone just tossed those on there, but in fact, there is a spreadsheet that says what each one corresponds to. And above the lines are some of the multibillion-dollar companies that resulted in these sectors.

So the diagram shows many key aspects of this really incredibly productive IT R&D ecosystem. And let me just note a few of them. First, research can take a long time before it pays off, in many of

those examples, 15 years from critical research advances to the first product introduction. Secondly, research often pays off in unanticipated ways. We are not very good at predicting where the biggest impact is going to be. Third, advances in one sector often enable advances in other sectors. It really is an interconnected network. Fourth, the research ecosystem is fueled by the flow of people and ideas back-and-forth between academia and industry. And finally, every one of these multibillion-dollar sectors has a clear relationship to federal research investment.

So it is important to realize—and you have heard it from the other two witnesses—that federal investment does not supplant private-sector investment; it complements it. Here is why: the vast majority of industry R&D is development, the engineering of the next release of the product. This is totally appropriate. Developing products is hard. Also, research takes many years to pay off in many cases. Even at Microsoft and IBM, which invest far more than any other IT companies in work that looks out more than one or two product cycles, this investment constitutes only about five percent of total R&D. At most companies it is 0 percent in IT.

Here is a great example—in addition to Kinect which you heard about from Dr. McKinley. It is this cute little iPad. Now, it is a product that maybe only Apple could have designed, just like Kinect is a clever product maybe only Microsoft could have designed, but every distinctive aspect of this device—the multi-touch interface, the sensors, the processor—has its origins in federally-sponsored research.

So IT R&D leads to exciting companies, but it does far more. It drives the economy, as you heard, directly through the growth of the IT industry, indirectly through productivity gains in other sectors.

Looking to the future—and Chairman Bucshon did a wonderful job of describing this in his introductory remarks—dramatic advances are necessary in meeting all of our national and global challenges; improved healthcare, advanced manufacturing, increased national and homeland security, revolutionizing transportation, personalized education—hopefully, we will talk about MOOCs in a minute—putting the smarts in the smart grid, driving advances in all fields.

Given the broad influence, it is not surprising that the demand for IT workers is strong. Dr. McKinley spoke to that clearly. What I would say is all STEM is important, but from a workforce point of view, all STEM is not created equal.

So to summarize, computing research changes our world, drives our prosperity, enables advances in all other fields, and is essential to meeting our national and global challenges. The government has played an essential role in fostering these examples. The future is bright. There is opportunity and need. There is also tremendous need for well-educated graduates. The government's role in supporting fundamental research is essential and doesn't supplant private sector investment.

Thank you very much.

[The prepared statement of Dr. Lazowska follows:]

TESTIMONY OF  
EDWARD D. LAZOWSKA  
UNIVERSITY OF WASHINGTON

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 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.<sup>1</sup> 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

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<sup>1</sup> *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.<sup>2</sup> Indeed, as the 2010 PCAST review of the NITRD program noted, "*all indicators – all historical data, and all projections – argue that [Networking*

<sup>2</sup> <http://www.infoworld.com/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.<sup>3</sup>

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.

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<sup>3</sup> 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.

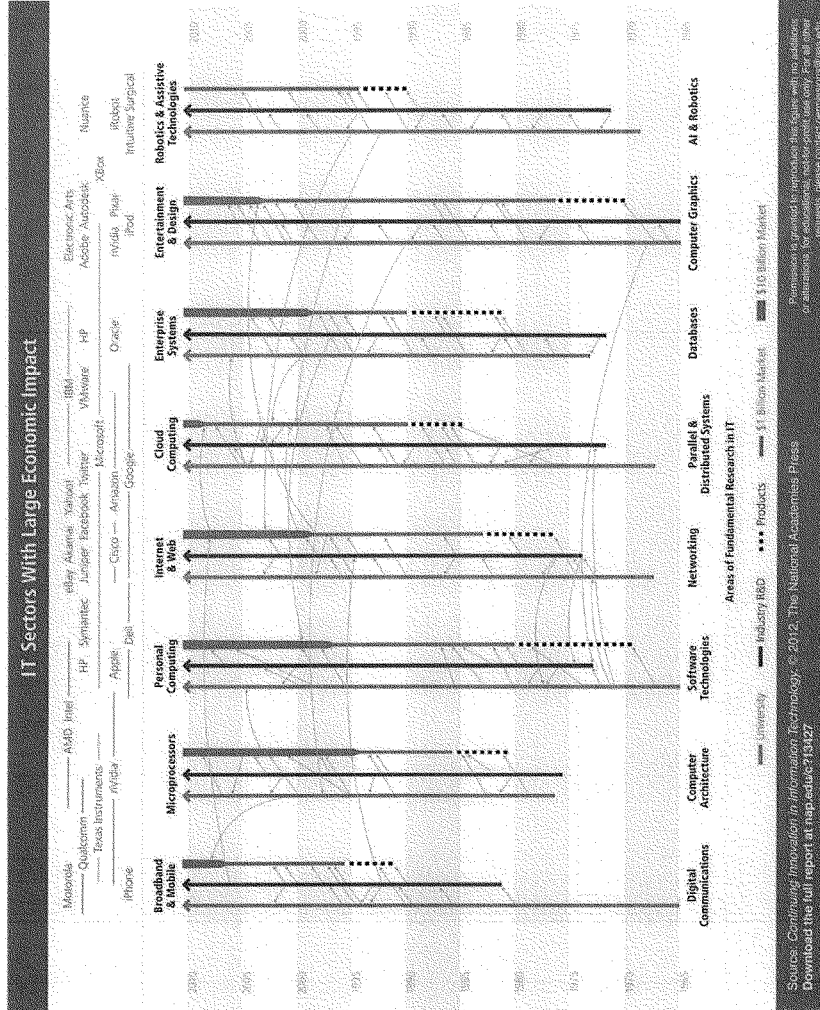
***Conclusion: Federal Investment in Information Technology R&D Has Yielded, and Will Continue to Yield, Extraordinary Payoff***

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

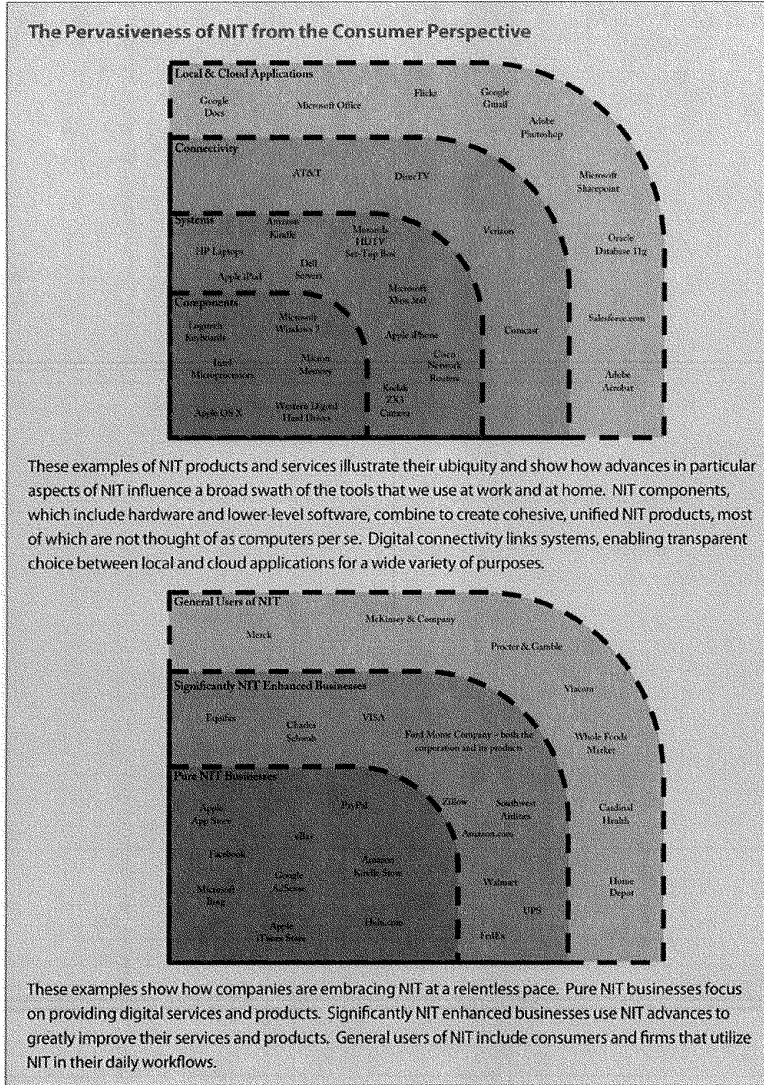
The Federal government has played an essential role in fostering these breathtaking advances. The Federal investment in computing research is without question one of the best investments our Nation has ever made. The payoff has been an explosion of new technologies that have touched nearly every aspect 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.





**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](http://www.nap.edu/catalog.php?record_id=13427)



**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>

Chairman BUCSHON. Thank you. And I would like to thank all the witnesses for their testimony and being available for questioning.

I want to remind Members that the Committee rules limit questioning to five minutes, and as Chair I will open and recognize myself for five minutes at this point.

I will some response from all of you on this one. In previous NITRD hearings, we have heard that IT's role in national security, national competitiveness, and national priorities is far broader than high-performance computing alone. As we continue to learn more about the recent National Intelligence Estimate Report regarding China's use of cyber espionage, can you expand on how the IT field has influenced or continues to influence national security? And whomever wants to go first. Dr. Lazowska?

Dr. LAZOWSKA. I will give it a try.

I think what has happened in the past 20 years is that high-performance computing is as important as it ever was and of ever-increasing importance, but what has happened is a set of other aspects of the field has risen to perhaps comparable importance. All right? So this was called the *High Performance Computing Act of 1991* because that was clearly the dominant aspect of the field in importance.

Now, where we stand in robotics, where we stand in mining vast amounts of data for intelligence purposes, all sorts of other aspects of the field are just as important to our security and to our competitiveness. So, for example, big data clearly matters in assessing threats. Artificial intelligence clearly matters in understanding communiques from other nations doing language translation, things like this. So in addition to information technology being important in countering all sorts of threats, it is a threat itself. All right?

So there has, as you noted, been lots of attention to cyber warfare recently. This is an area where, honestly, we lag behind. That is, the aggressors have an advantage over the defenders and we have been defending for decades with what I have to say are heroic Band-Aid efforts. And we need to really rethink the design of our systems to make them more secure. And that is a research challenge.

Chairman BUCSHON. Thank you.

Anyone else have—

Dr. MCKINLEY. So I would just like to add to Ed's remarks that 20 years ago, defense was driving IT. We had big investments in technologies that were really directly applicable to defense, but because of the rise in industry and consumer products that use IT, we now have a huge influence on the capabilities of defense, driven by capabilities of things you also want to buy. And so, for example, a Smartphone is very helpful to a soldier as well as helpful to you when you are trying to get your kids to their hockey games. So that the driving of what technologies you want to use in the field, as well as the technologies that are useful for consumers have come together. And this is where the narrowing of the gap is a problem because you want to have better capabilities. And that requires being ahead of the game and being ahead of industry as well and ready with the new technologies.

Chairman BUCSHON. Dr. Gaither?

Dr. GAITHER. Yes, so I would like to just address it very briefly. I would not look at this as an either/or problem. So I think it really does—I guess it goes back to my point about interdisciplinary work. I think you should look at it as a combination of high-performance computing, as a combination of the data mining. Clearly, that is going to play a very large role. But I would look at it as a portfolio of tools to solve this problem, not one versus the other.

Chairman BUCSHON. Great. Thank you. I will now recognize Mr. Lipinski for five minutes.

Mr. LIPINSKI. Thank you. I will let you continue on—since you started talking about cybersecurity, I will jump to that question. Obviously, it is a big issue becoming bigger, and I think we are going to learn, unfortunately, maybe in a dramatic fashion how critical it is to us right now.

I cosponsored a bill last Congress with Congressman McCaul called the *Cybersecurity Enhancement Act*. We are going to be introducing that again. Among other things, it would require a federal strategy for assessing cyber threats and coordinate cyber R&D to address these threats. Part of the 2013 PCAST report on NITRD recommended greater coordination among agencies on cybersecurity R&D. In what ways do you think—you touched on this little bit—what ways do you think the Federal Government could better coordinate research efforts in cybersecurity? Dr. Lazowska?

Dr. LAZOWSKA. One comment I would make is that all of these studies have found that NITRD is one of the most successful coordination efforts. So I think we have to state that at the outset. In cybersecurity, there is a particular challenge because of classification. And I think an important issue is attempting to distill the essence of classified problems so that a broader range of investigators can work on them. All right?

So most universities don't do classified research, but many of the best cybersecurity researchers are in universities. I know that DARPA has worked on this. The National Science Foundation, of course, supports a large number of research programs in sort of the unclassified core of cybersecurity. But honestly, it is an area that needs a better research workforce, as well as a better practitioner workforce.

I would like to mention one additional reason why this is so important, and that is every aspect of our Nation's critical infrastructure is now controlled by computer systems. All right? So this just ten years ago was much less so for, let us say, the power grid, all right? These days, all of these are complex, interconnected systems subject to attack from information technology in ways that can actually damage hard-to-replace physical infrastructure. So we truly do need more communication and collaboration among the agencies.

The Senior Steering Group that NITRD has created in the past couple of years since the 2010 report has gone a long way towards addressing the coordination issues.

Mr. LIPINSKI. Any other comments? I will move on. Okay, great. All of you are computer scientists. I actually have a background as an engineer but also in—with the dark side got my Ph.D. in polit-

ical science. I am also a social scientist. In your testimony, you all discussed the need for computer scientists to collaborate with social scientists to address many scientific and technological challenges. Can you elaborate on the role of social and behavioral scientists do and should play in NIT R&D? And are there sufficient federal mechanisms to support multidisciplinary collaboration among computer scientists, engineers, and social scientists?

Let me say that I know there is a lot of bad social science research out there, but I think, unfortunately, it is all getting lumped together and attempted to be thrown out. But can you talk to the role that social and behavioral scientists can play in NIT R&D? Dr. McKinley?

Dr. MCKINLEY. Humans interact with computers, so if we don't understand how humans want to interact with them, if we don't understand the social sciences, if it is not a collaboration, we can't make IT work for people because it is about the people. And yes, there is bad research in every area unfortunately, but there is mostly good research. And a great example is health. If you want to make people—or if you want to use your cell phone that you are carrying around to help you be healthier, we might want to remind you to take a walk or eat better, but we don't want you to—we need to understand how those hints help you or maybe they discourage you and you get mad at your phone and you stop doing it. So some of these basic issues on how you use IT for health require both doctor collaborations, user interface, and people who understand how human beings make decisions.

Mr. LIPINSKI. Dr. Gaither?

Dr. GAITHER. So to further that point, visualization is all about really verifying visualizations. We can't really do that quantifiably right now. So we do them with user studies because visualization is about how people perceive the images that they are seeing.

I also want to address the point about the interdisciplinary research. So I do think that there is a frightening shortage of funding going into interdisciplinary research. And let me say, while it may be a little cliché, the sum of putting people together from different backgrounds really is greater than the individual parts. And I think the magic happens when you put people together from very different backgrounds working towards a common goal.

Mr. LIPINSKI. Thank you very much. I am out of time. I yield back.

Chairman BUCSHON. I recognize Mr. Stockman for five minutes.

Mr. STOCKMAN. I have kind of a concern because I am hearing an underlying theme about cybersecurity. And I guess I would go through the three of you doctors who are professionals and tell us, hey, how much—if we need more funding, how much more funding do we need for cybersecurity to defend against it? And two, are we doing enough work towards that? I was shocked—I was at a Chevron gas station and actually the gasoline pumps were shut down because of a cyber attack. And I don't think people realize to what degree, how deeply we are dependent upon computers and satellites. I guess I would go through and tell us from our job—to do our job right, are you getting enough funding? And how much is enough and what do we need to do?

Dr. LAZOWSKA. I am not going to be able to answer your question in specific terms I am afraid. There had been numerous calls for greater investments in fundamental research in cybersecurity. I think now, we are spending enormous amounts of money in short-term defenses, which are holding the threats at bay largely, although not entirely as you point out. We are not spending enough laying the groundwork for systems that are designed in a way that they will actually be resistant to attack. So the problem is that you can't just bolt security on to a complex hardware/software system at the last minute after it has been designed in an insecure way. We have learned a huge amount in the past ten years about how to build reliable and secure systems. Microsoft has in fact been a leader in this. The quality of Microsoft's code and its resistance to penetrations has improved enormously in the past decade. But we do need significantly greater investment in the fundamentals.

I was the co-chair of the late PITAC, President's Information Technology Advisory Committee, under President Bush. We wrote a report on cybersecurity that called for significantly increased investment in the National Science Foundation and other agencies, and we didn't get reappointed as a reward for our efforts. It is a serious issue.

Mr. STOCKMAN. I don't mean to interrupt but when you say significant, is there a number that you targeted or suggested?

Dr. LAZOWSKA. Unfortunately, the problem is that it is a portfolio. You need an investment in the long-range work. You need to continue the investment in blocking threats, and you need to span—

Mr. STOCKMAN. But I mean is there a price tag that we can—I mean we have to—

Dr. LAZOWSKA. We called eight years ago for an investment of, I believe, another \$90 million at the National Science Foundation, which I view as a tiny amount of money relative to the potential cost of insecurity. But you do have to realize that the payoff from that investment would be some number of years down the road.

Mr. STOCKMAN. That is more than what they have stolen from some banks through—

Dr. LAZOWSKA. Less than they have stolen from some banks.

Mr. STOCKMAN. Yes, that is what I meant. Yes, that is what I am saying—

Dr. LAZOWSKA. It is less than what they have stolen from some gas stations, I am sure—

Mr. STOCKMAN. Yes, exactly.

Dr. LAZOWSKA. This—it is a very serious issue, sir.

Mr. STOCKMAN. In fact, I think in 10 seconds we probably—less than that, we have spent that.

Dr. McKinley, I have a question for you. You actually worked—and I have got to hurry up because we are out of time—but you worked with the private sector or you have. You also had federal and state. Which in your opinion do you see the most efficiency? If we had appropriated money, where would you put that funding?

Dr. MCKINLEY. So different research needs to be done at different times and different places. So one of the reasons I moved from academia to Microsoft Research is because many of the problems that I work on, such as making your phone last longer and

runtime systems, which I won't tell you exactly what that means, but that right now these areas are turning into actionable products and things that people want to use. And so right now is the right time for some of the groundwork that my research laid to move into industry. And it is that flow of people who come with their ideas and their expertise that makes the whole system work. Like I loved academia. I might go back someday, but this is the right place for me to be right now. And that ecosystem is represented by my career and as a grad student my first funding was National Science Foundation, a Science and Technology Center, which was a big bet on parallel computing, and that is technology we really need today, and I am still an expert in that area.

Chairman BUCSHON. Gentlemen yields back.

Ms. Esty, you are recognized for five minutes.

Ms. ESTY. Thank you very much. You have all described how important federal investments are in NITRD to this country. And as you know, we face a rather challenging budgetary climate right now. For Dr. McKinley, the questioned frequently arises, you know, why can't more of this be done out of the private sector? So if you can talk about what you think the implications are if we continue to cut back on basic R&D, what is the likelihood that Microsoft or other private companies would fill in the gap of the research that now is being done on basic R&D?

Dr. MCKINLEY. So most companies aren't making even the modest investment that Microsoft is making. A startup company takes some ideas that are in a university and doesn't exist until those ideas exist and then they become a billion-dollar industry and a competitor of Microsoft's, like Google. So those kinds of activities just won't happen in big established companies, even ones that believe as strongly in research and the research ecosystem as Microsoft.

Ms. ESTY. I would also like you—all three of you have mentioned the importance of education. I have a junior in college who is doing computer science and astrophysics. But there are not many girls in his class, I will tell you that, very few young women. Could you talk about what you see as the opportunities and what actually we can be doing particularly at the younger ages? What can we be doing in this country, if we are going to get U.S. competitiveness, which is this long pipeline? And as he tells me, Mom, these classes are really hard. I could be doing much better in economics or in my major, political science, but, you know, computer science and physics are really hard. So what can we—your insights, what can we do with MOOCs, with other things? What should we be doing as a country and how does R&D fit into that?

Dr. MCKINLEY. So we have to have better math and IT education. Right now, computer science is—the AP class is only taught in five percent of high schools across the country. If people, especially women and minorities, don't have exposure to computer science as high school students, they never decide to pick it up in college anymore, because now, there is a dichotomy of skills and they feel like they are already behind because it is a hard major. And so I think what we need to be doing is prepping more of our students in high school to have the skills that at least it is a choice

for them. So more rigorous math and science classes and the preparation, the right sets of skills so that they can do them.

Dr. LAZOWSKA. A comment that I think is important is that computer science needs to be viewed as part of STEM. In the State of Washington, where I am, it is part of essentially commercial education. It is in there with woodshop and metal shop and cooking and, you know, I took print shop when I was in high school in Washington, D.C., but I don't use it a lot today. Every student going forward needs to understand what we call computational thinking. Every field, whether it is biology or sociology, is utilizing computational thinking. That is models and algorithmic expression and decomposing problems into pieces you can solve and assembling and testing those results. We do this in our daily lives.

So I think of programming as the hands-on inquiry-based way in which we teach computational thinking. It can be an end in itself but at the K to 12 level, computational thinking as part of STEM embodied in AP computer science, which uses programming as an inquiry-based way to teach that, is critical for all students.

Dr. GAITHER. So this is a subject I am pretty passionate about. And we lose a shocking number of our young girls around third or fourth grade and we never get them back. I have a daughter that is struggling right now as a junior to decide whether she wants to go into a STEM field or into art. It is really that far apart. I think we need to be a little more aggressive and get funding streams to connect what is going on in the undergraduate population and go all the way back into the educational pipeline as far back as third grade and get them thinking about the computational thinking but also give them examples. Why are we doing this? Why do we care? How will it benefit society? In my experience, the young girls that I have worked with, once you educate them about how it is going to impact society, they are all on board. They are interested.

Dr. MCKINLEY. So I just want to add the creativity part of computer science is often undervalued and that we want our young people to know that they can be creators of technology; it is not just consumers and users of it. And that it is now easy with some of the technologies such as robotics, Kinect, and other things to really help them if we provide some educational tools to go along with some of these technologies to help them see how to satisfy their needs for creativity in this field, which is very exciting.

Dr. LAZOWSKA. I wanted to say one word about MOOCs, which is something that you raised and other Members have raised. The notion that what you learn in college lasts you for a lifetime, that is a notion we left behind in the 20th century. So one thing MOOCs do is give you the opportunity to pick up knowledge that you need throughout your lifetime. I think there is an enormous amount of work to be done in understanding exactly how people learn through MOOCs and figuring out how to use the large-scale data to understand how people learn and how we can teach them better.

We just ran a workshop the past two days in Washington, D.C., on exactly this subject, which is what is the science that we can do in this online scalable world to understand how to teach and learn better? So I think there are enormous opportunities here, particularly for lifelong learning. The jury is still out on whether it dramatically changes the four-year college experience or K to 12.



Chairman BUCSHON. Thank you very much. Yeah, in the area of education—I will make a brief comment—there is a program in Indiana, in Indianapolis, called Project Lead the Way. I don't know if anyone has ever heard of that. But they are doing exactly what some of you are talking about in high schools around the country, a lot in Indiana, especially in Evansville where I live, and focusing on engineering education, hands-on, and how children and young adults learn better. If we can show them exactly what you all have said, how it impacts them and not just have it on a sheet of paper, so that is very important.

I will now go into a second line of questioning. We have votes coming up at three o'clock but I think we have time for a second round of questioning. So I will yield to Mr. Lipinski.

Mr. LIPINSKI. Thank you, Mr. Chairman. I always have to mention—I do mention I have two degrees in engineering but I always have to say that my wife has a degree in math, so we cover a few of the STEM fields there.

I want to give Dr. Lazowska his opportunity here to do his very short version of walking us through the—something you had mentioned, talking about the technology that Apple pulled together to develop the iPad, how they originated with federal research investments. So you are going to get 4 minutes to do this. We have had this done—you posted a briefing before for the Committee on this, but can you give us a short version right now? Just show us how federal research wound up in this device.

Dr. LAZOWSKA. Thank you so much. Here are just a couple of examples. The multi-touch interface, this is the sort of zoom with your fingers, goes back to federally supported research. And in fact, in the late 1990s, Apple acquired a company spun out from the University of Delaware with federal funding in which this multi-touch gestural interface work was done. And that became the interface on the original iPhone and now on the iPad. That is one example. One of the great things about this device is the suite of sensors. There is a GPS, there is a compass, things like that, that tell you where you are, make driving directions work in your GPS unit or in your iPad or iPhone or Windows Phone I have to say. And these sensors go back to physics research in the 1930s, all right, which led to things like the atomic clocks which make the satellites work and eventually the GPS that we deployed in satellites. The miniaturization driven through the NITRD program of these components makes it possible to put it in a phone or a device like this.

Academic and industry research—much of the academic research funded by the Federal Government has changed the way we design integrated circuits and the very architecture of the microprocessors. This is Dr. McKinley's—one of her specialties. But we designed microprocessors, including the one in this device, in an entirely different way to an entirely different architecture than we were doing before the NITRD investment. I could go on and on and I appreciate the opportunity, but the important thing is the ideas in this device go back in some cases to basic research 80 years.

Mr. LIPINSKI. Thank you. And maybe we could do another—maybe come in again. I know some new Members of the Committee maybe come in and get the extended version of—

Dr. LAZOWSKA. We would welcome the opportunity. Thank you.

Mr. LIPINSKI. And since you didn't take up all the 4 minutes, I wanted to throw out another question just in general about ideas about how can MOOCs help STEM education? How do you see those? Briefly, what are your thoughts on that? Dr. McKinley?

Dr. MCKINLEY. So the reason the jury is out on MOOCs is because we know that interactive activities with a great teacher who inspires you, with someone who sees what you are doing wrong as you try to work the problem, is one of the most effective ways to get people excited and to educate them. So my kids are seeing a flipped classroom right now where you have a lecture from your regular teacher and then in the classroom you are doing the example problems or working through a worksheet, and so then, the teacher is watching you.

So I feel like that that is probably the most effective way that we are going to see MOOCs, so you have the best lecturer in the world, so people have polished this to be perfect, and then you have tutors or your teacher is now doing the hands-on watching how you understood, what kind of educational experience that you need. Because although many computer science lectures have just the professor talking at the front of the room, that is not where you really learn how to do computer science.

So it has to be a mix of these different learning styles and MOOCs, I think, are going to have a role perhaps mostly in lifelong learning with very motivated people who already learned their learning style. But I think in terms of MOOCs having a huge effect on my 11-year-old, I don't think that is going to motivate him to do his math homework.

Mr. LIPINSKI. I think there is a lot more to say here but just for my colleagues I think may have some questions, I am going to yield back right now, and hopefully, we could come back to this another time.

Chairman BUCSHON. Thank you. I yield to Mr. Stockman.

Mr. STOCKMAN. I just have a quick question. This to me is really phenomenal about computer security and everything. And as you can tell from the line of questioning, I think it weighs on a lot of our minds. And the Administration and Congress got \$800 billion or some people say 1 trillion in stimulus money. Did any of you receive any of that or request any of that funding for computer security?

Dr. MCKINLEY. I got some of that money.

Mr. STOCKMAN. How much did you get?

Dr. MCKINLEY. I got \$500,000 and I employed four graduate students over the three courses of the year, and those people are working at Intel, Facebook, and Google. And one of them is a professor. So that helped create jobs because I was able to hire graduate students and they are highly trained and—

Mr. STOCKMAN. Was—excuse me. I apologize. We are running short, close to vote, but was it specifically for computer security?

Dr. MCKINLEY. So this research spanned computer security and computer systems, which I think is this intersection of these two areas.

Mr. STOCKMAN. Well, I am wondering because in terms of money, in terms of government, you mentioned \$90 million. That seems nominal for such an important critical—I mean our infrastructure

is so dependent upon it, it is kind of, I don't know, bizarre that we don't spend more money defending the life system of this nation.

Dr. MCKINLEY. The issue with cybersecurity is that it is not just something, as Ed pointed out, that you can Band-Aid on—

Mr. STOCKMAN. Right, full-time—

Dr. MCKINLEY. —it has to be—you have to have it as part of the whole system that you are building. And so it is not going to be solved just by the people who are only experts in security working on it. It has to be partnership between people who work on runtime systems and power efficiency and designing architectures. These people have to work together and design from the get-go. And so it is not enough to just say, oh, we are going to explode the amount of money in computer security, because the way you make these partnerships is much more complicated and it requires a richer risk portfolio that has a lot of investments in different areas to get people to partner with them.

Mr. STOCKMAN. But Dr. McKinley, what I am saying from our standpoint, it would be helpful if we had some guidance because I think this is very critical to our infrastructure. And I appreciate you coming out today and I look forward to more guidance and how we can help you secure our Nation's lifeblood. I really appreciate all your help.

Dr. MCKINLEY. So then these large multidisciplinary projects where you are saying let us make some software systems more secure, let us make architectures more secure, so it is a partnering of people who are experts on cybersecurity and people who are experts on that topic area that you are trying to make more secure. I think those broad, multidisciplinary, big-bet kind of investments that NSF has done very well in several instances, including under my graduate career are the ways to make that happen. And that is much more complicated than just saying we are going to throw a ton of money at cybersecurity and good luck. And we don't care if you partner with anyone.

Mr. STOCKMAN. Well, I don't know about saying good luck. But I was actually following up on—

Dr. MCKINLEY. No, no—

Mr. STOCKMAN. —his comments that it was \$90 million. And I thought in terms of our goals and our objectives, I think \$90 million would have been very wisely spent if we gave it to you.

Chairman BUCSHON. Thank you. And I—unless you want to comment on that.

Dr. LAZOWSKA. All I can say is that I agree with Dr. McKinley and with you. There are some areas of critical importance where we need greater investment, and it is important to realize that the federal investment in fundamental research is multiplied so many times over in its impact over the long term.

Mr. STOCKMAN. And I agree with you. I just wish we allocated billions instead of millions. Thank you. I yield back.

Chairman BUCSHON. Gentleman yields back.

Ms. Esty?

Ms. ESTY. Thank you. Yes, I would like to follow that up a little bit because it seems to be part of this is the inherent tension between what we do, which tends to be dealing with the urgent; and the important, which is the long-term R&D. And so how we get the

marriage of those two so that we address these important problems, Dr. Lazowska, you talked about the importance of patience in basic R&D.

And we are facing—Representative Stockman and I sat in on the same briefing by General Alexander, which was completely terrifying to us about how incredibly vulnerable we are at every level and we haven't even really talked about the energy grid, which is truly stupefyingly terrible because we know they don't even have systems that are 20 years old. They are older than that right now. So that is a different order of challenge because they aren't even operating the way they ought to be, much less are they secure.

So if any of you have thoughts on how we balance this need for problem-solving about these urgent, immediate needs and yet also fund basic research that we can't exactly say where is it going to lead but we do know it is going to lead to these important innovations down the road.

Dr. LAZOWSKA. I am afraid this is why we vote for you. These are very difficult challenges.

I will say that shortly after September 11, 2001, I was on a National Academies panel that looked at IT R&D relative to national security, and what we concluded was precisely that investments in protecting our vast infrastructure that relies on computing are much more important than my inability to buy from Amazon one afternoon because the Internet is down. All right? So every element of our critical national infrastructure relies now inherently on information systems. And we have to recognize that does represent a huge vulnerability.

Chairman BUCSHON. All right. I would like to thank the witnesses for their valuable and very interesting testimony. And I have one of those new Xboxes by the way. My kids love it. It is just awesome. Got it for Christmas.

There are Members of the Committee who may have additional questions for you and we will ask that you respond to those in writing. The record will remain open for two weeks for additional comments and written questions from the Members. The witnesses are excused and the hearing is adjourned. Thank you.

[Whereupon, at 3:02 p.m., the Subcommittee was adjourned.]

