OVERSIGHT OF THE NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT PROGRAM AND PRIORITIES FOR THE FUTURE

HEARING

BEFORE THE

SUBCOMMITTEE ON RESEARCH AND SCIENCE EDUCATION

COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY

HOUSE OF REPRESENTATIVES

ONE HUNDRED TWELFTH CONGRESS

FIRST SESSION

WEDNESDAY, SEPTEMBER 21, 2011

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Wednesday, September 21, 2011

OVERSIGHT OF THE NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT PROGRAM AND PRIORITIES FOR THE FUTURE

WEDNESDAY, SEPTEMBER 21, 2011

HOUSE OF REPRESENTATIVES,
SUBCOMMITTEE ON RESEARCH AND SCIENCE EDUCATION,
COMMITTEE ON SCIENCE, SPACE, AND TECHNOLOGY,
Washington, DC.

The Subcommittee met, pursuant to call, at 2:04 p.m., in Room 2318 of the Rayburn House Office Building, Hon. Mo Brooks [Chairman of the Subcommittee] presiding.

RALPH M. HALL, TEXAS
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Oversight of the Networking and Information Technology Research and Development Program and Priorities for the Future

Wednesday, September 18, 2011
2:00 p.m. – 4:00 p.m.
2318 Rayburn House Office Building

Witness List

Dr. George Strawn

Director, National Coordination Office, Networking and Information Technology Research and Development (NITRD) Program

Dr. Edward Lazowska

Director, eScience Institute/Bill and Melinda Gates Chair, University of Washington

Dr. Robert Sproull

Director of Oracle Labs, retired

Dr. Robert Schnabel

Dean, School of Informatics, Indiana University

HEARING CHARTER

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

Oversight of the Networking and Information Technology Research and Development Program and Priorities for the Future

WEDNESDAY, SEPTEMBER 21, 2011

2:00 P.M.—4:00 P.M.

2318 RAYBURN HOUSE OFFICE BUILDING

Purpose

On Wednesday, September 21, 2011, at 2:00 p.m. the Subcommittee on Research and Science Education will hold a hearing to review the networking and information technology research and development (NITRD) program to ensure U.S. leadership in networking and information technology and to discuss priorities for the future.

Witnesses

- Dr. George Strawn, Director, National Coordination Office, Networking and Information Technology Research and Development (NITRD) Program
- Dr. Edward Lazowska, Bill & Melinda Gates Chair in Computer Science & Engineering, University of Washington
- Dr. Robert Sproull, Director of Oracle Labs, retired
- Dr. Robert Schnabel, Dean, School of Informatics, Indiana University

Overview

- Advances in networking and information technology (NIT) continue to transform the world in which we live. We increasingly rely on the systems, tools, and services of this ever-growing and ever-changing domain. It is not only as a matter of convenience in our daily lives, but critical to our future economic prosperity, health, and security.
- The Networking and Information Technology Research and Development (NITRD) Program is the federal government's mechanism for coordinating the Nation's unclassified NIT research and development (R&D) investments. NITRD's formal membership consists of 14 federal agencies while many additional agencies participate in program activities.
- NITRD was originally authorized in the High-Performance Computing Act of 1991 to help coordinate ongoing high-performance computing programs throughout the federal government. The Act was amended in 1998 and 2007. In the 111th Congress, the U.S. House of Representatives passed the Networking and Information and Technology Research and Development Reauthorization Act twice. The Senate did not take up H.R. 2020 and removed the language in the 2010 America COMPETES Reauthorization Act.
- As required by law, in December 2010, the President's Council of Advisors on Science and Technology (PCAST) released its report, *Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology*. The report finds that "NITRD is well coordinated and that the U.S. computing research community, coupled with a vibrant NIT industry, has made seminal discoveries and advanced new technologies that are helping to

meet many societal challenges," but also notes the need for more accurate accounting and additional investments in basic research. [1]

- The Fiscal Year 2012 (FY 12) budget request for agency programs captured under NITRD is $3.9 billion, roughly $200 million more than the FY10 actual amount.

Background

Federal support for research and development in networking and information technology (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 global competition. Now, several decades after the dawn of the digital revolution, NIT encompasses a broad array of technologies from smart phones to digital libraries and cloud computing. Having changed the way we listen to music, drive our cars, and communicate with each other, this ever-growing field has led to the creation of many of the technologies and systems we rely on daily.

Additionally, research and development (R&D) in NIT provides a greater understanding of how to protect essential systems and networks, 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.

Networking and Information Technology Research and Development Program (NITRD)

The Networking and Information Technology Research and Development (NITRD) program is the main federal R&D investment portfolio in networking, computing, software, cybersecurity, and related information technologies. NITRD coordinates this unclassified R&D across 14 federal agencies (see Table 1).

[1] President's Council of Advisors on Science and Technology, Report to the President and Congress December 2010,*Designing a Digital Future: Federally Funded Research and Develpment in Networking and Information Technology*, p.v.

Table 1[2]
NITRD Member Agencies
The following Federal agencies, which conduct or support R&D in advanced networking and information technologies, report their IT research budgets in the NITRD crosscut and provide support for program coordination:
Agency for Healthcare Research and Quality (AHRQ)
Defense Advanced Research Projects Agency (DARPA)
Department of Energy/National Nuclear Security Administration (DOE/NNSA)
Department of Energy/Office of Electricity Delivery and Energy Reliability (DOE/OE)
Department of Energy/Office of Science (DOE/SC)
Department of Homeland Security (DHS)
Environmental Protection Agency (EPA)
National Aeronautics and Space Administration (NASA)
National Archives and Records Administration (NARA)
National Institute of Standards and Technology (NIST)
National Institutes of Health (NIH)
National Oceanic and Atmospheric Administration (NOAA)
National Science Foundation (NSF)
National Security Agency (NSA)
Office of the Secretary of Defense (OSD) and Department of Defense (DoD) Service Research Organizations (Air Force, Army, Navy)

Additional agencies that do not contribute funding also participate in NITRD planning activities (see Table 2).

Table 2[3]
NITRD Participating Agencies
Representatives of the following agencies with mission interests involving networking and information technology research and development and applications are active participants in NITRD activities:
Defense Information Systems Agency (DISA)
Department of Energy/Office of Electricity Delivery and Energy Reliability (DOE/OE)
Department of Health and Human Services/Office of the National Coordinator for Health Information Technology (HHS/ONC)
Department of State (State)
Department of the Treasury (Treasury)
Department of Transportation (DOT)
Federal Aviation Administration (FAA)
Federal Bureau of Investigation (FBI)
Federal Highway Administration (FHWA)
Food and Drug Administration (FDA)
General Services Administration (GSA)
Intelligence Advanced Research Projects Agency (IARPA)
National Telecommunications and Information Administration (NTIA)
National Transportation Safety Board (NTSB)

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[2] The Networking and Information Technology Research and Development Program Supplement to the President's FY 2012 Budget, p. vi

[3] The Networking and Information Technology Research and Development Program Supplement to the President's FY 2012 Budget, p. vi

Nuclear Regulatory Commission (NRC) U.S. Department of Agriculture (USDA) U.S. Geological Survey (USGS) Veterans Administration (VA)

The NITRD program has played a role in several important technological advances including the computational decoding of the human genome; modeling and simulation of complex physical systems (aircraft, automobiles, power grids, and pharmaceuticals); unmanned aerial vehicles, search-and-rescue robots; and computer-based education and training.

The Subcommittee on NITRD of the National Science and Technology Council (NSTC) is the internal deliberative organization for NITRD policy, program, and budget guidance. The NITRD Subcommittee includes representatives from each participating agency, as well as the Office of Management and Budget (OMB). The Subcommittee coordinates the planning, budgeting, implementation, and reviews of NIT R&D across the NITRD member agencies to help assure continued U.S. leadership, satisfy the needs of the federal government for advanced IT capabilities, and accelerate development and deployment of new technologies.[4]

NITRD research activities are organized in eight Program Component Areas (PCAs). The PCAs also align the NITRD program budget categories. The eight PCAs include: Cybersecurity Information Assurance (CSIA); Human Computer Interaction and Information Management (HCI & IM); High Confidence Software and Systems (HCSS); High End Computing Infrastructure and Applications (HEC I&A); High End Computing Research and Development (HEC R&D); Large Scale Networking (LSN); Software Design and Productivity (SDP); and Social, Economic, and Workforce Implications of IT and IT Workforce Development (SEW).[5] However, NITRD research areas and activities shift regularly as the NIT field creates and develops new R&D challenges.

The NITRD National Coordination Office (NCO) provides staff support for the NITRD program. The NCO provides program and financial management services, technical and subject matter expertise in facilitation, strategic planning, technical writing, networking and information technology services, and administrative staff support for the NITRD Subcommittee and other NITRD subgroups. The National Science Foundation (NSF) serves as the host agency for the NCO.[6]

Legislative History

Congress originally authorized NITRD in the High-Performance Computing Act of 1991 (P.L. 102–194), after recognizing that a number of federal agencies had ongoing high-performance computing programs without a coordinating body. The Act established that coordinating body to improve interagency coordination, cooperation, and planning among those agencies with high-performance computing programs. In addition, it authorized a multi-agency research effort, called the High-Performance Computing and Communications program, to accelerate progress in the advancement of computing and networking technologies and to support leading edge computational research in a range of science and engineering fields. The statute established a set of mechanisms and procedures to provide for the interagency planning, coordination, and budgeting of the research and development activities carried out under the program. The Act has since been amended through the Next Generation Internet Research Act of 1998 and the America COMPETES Act of 2007.

In 2007, the America COMPETES Act amended the existing statute in several ways:

- Specified that the external advisory committee for the program must carry out biennial reviews of the funding, content and management of the interagency R&D program and report its findings to Congress;
- Required the Office of Science and Technology Policy (OSTP) to develop and maintain a roadmap for developing and deploying high-performance computing (high-end) systems; and

[4] About the Subcommittee on Networking and Information Technology Research and Development (NITRD Subcommittee), *http://www.nitrd.gov/subcommittee/program.aspx.*

[5] NITRD Program PCA Definitions, *http://www.nitrd.gov/subcommittee/pca-definitions.aspx.*

[6] About the Subcommittee on Networking and Information Technology Research and Development (NITRD Subcommittee), *http://www.nitrd.gov/subcommittee/program.aspx.*

- Clarified that grand challenge problems supported under the interagency program are intended to involve multidisciplinary teams of researchers working on science and engineering problems.

NITRD Reauthorization in the 111th Congress

In the 111th Congress, the U.S. House of Representatives passed H.R. 2020, the National Information and Technology Research and Development Reauthorization Act. (See Appendix A for details.) The bill sought to prioritize and strengthen federal information technology activities across the federal government by:

- Improving program planning and coordination through strategic planning and an Advisory Council with appropriate policy and technical expertise;
- Rebalancing portfolios to focus less on short-term goals and more on large-scale, long-term, interdisciplinary research with the potential to make significant contributions to society and U.S. competitiveness;
- Requiring the program to support R&D in cyber-physical systems and human-computer interactions, visualization, and information management, including the convening of a university/industry task force to explore collaborative R&D activities with participants from universities, federal labs, industry and other partners; and
- Formally codifying the role of the NCO and specifying the source of funding for the office.

The Senate did not act on this legislation. H.R. 2020 was also made a part of the House-passed America COMPETES Reauthorization Act of 2010, but the language was removed by the Senate before enactment.

2010 PCAST Report on NITRD

In December 2010, the President's Council of Advisors on Science and Technology (PCAST) completed a legislatively required report on NITRD. The report, *Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology*, found that "NITRD is well coordinated and that the U.S. computing research community, coupled with a vibrant Networking and Information Technology (NIT) industry, has made seminal discoveries and advanced new technologies that are helping meet many societal challenges." [7]

The 2010 report made several assessments about the role of the NIT field in answering the Nation's challenges and priorities:

- Advances in NIT are a key driver of economic competitiveness. They create new markets and increase productivity.
- Advances in NIT are crucial to achieving our major national and global priorities in energy and transportation, education and life-long learning, health care, and national and homeland security.
- Advances in NIT accelerate the pace of discovery in nearly all other fields.
- Advances in NIT are essential to achieving the goals of open government. [8]

Stressing the need that federal investments be in NIT basic research, since the private sector is heavily involved in the development side, the report suggests that an investment of at least $1 billion annually will be required for new, potentially transformative research. The report also recognizes that in the current economic uncertainty, repurposing and reprioritization of funding will be necessary, but does not rule out new funding and indicates a lower level of investment "could seriously jeopardize America's national security and economic competitiveness." [9]

The PCAST report includes recommendations for increased investments in long-term, multi-agency research initiatives in health, energy and transportation, and cybersecurity. It emphasizes, "Where fundamental NIT advances are needed to support these initiatives, mission agencies should invest in fundamental research in

[7] President's Council of Advisors on Science and Technology, Report to the President and Congress December 2010, *Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology*, p. v.

[8] President's Council of Advisors on Science and Technology, Report to the President and Congress December 2010, *Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology*, p. vii.

[9] Ibid., p. x.

NIT, either alone or in collaboration with NSF, and should not limit their programs to application-specific research."[10]

The report also calls for exercising leadership to bring about changes in K–12 STEM education; enhancing the effectiveness of government coordination of NIT research and development; and redefining NITRD budget categories to separate NIT infrastructure for R&D in other fields from NIT R&D.

With specific regard to education, the report finds that "NIT is the dominant factor in America's science and technology employment, and that the gap between the demand for NIT talent and the supply of that talent is and will remain large."[11] The report recommends increasing the number of graduates in NIT fields at all degree levels and calls for the inclusion of computer science in K–12 education.

NITRD Fiscal Year 2012 Budget Request

In February 2011, NITRD released its Supplement to the President's Budget request. The Supplement is a summary of the NITRD research activities planned and coordinated for Fiscal Year 2012 (FY 12) for each of the participating agencies. The NITRD request totals $3.9 billion for FY 2012, a 1.9 percent increase from FY 10 expenditures, and reflects many spending priorities recommended in the PCAST report.

The NITRD Supplement breaks down budget requests for each of the 14 federal agencies involved in NITRD according to the PCAs. [12] (See Appendix B for details.)

For agencies within the jurisdiction of the Committee on Science, Space and Technology, the budget request totals are reflected in Table 3:

Table 3[13]

NITRD FY12 Budget Request, by Agency
(dollars in millions)

Agency	**FY10 Actual**	**FY12 Request**
NSF	1105.6	1257.7
DOE*	418.4	529.9
NIST	81.0	133.9
NASA	85.3	94.7
NOAA	26.3	26.3
DOE/NNSA	29.6	25.9
EPA	6.3	5.9

*Includes Office of Science and Office of Electricity Delivery and Energy Efficiency

[13] The Networking and Information Technology Research and Development Program Supplement to the President's FY 2012 Budget, p. 28

Major changes in investments for agencies within the Committee's jurisdiction include a $152 million (14 percent) increase for the National Science Foundation (NSF). This amount includes $35 million for High End Computing R&D for nanotechnology research and the Science, Engineering, and Education for Sustainability (SEES) effort and investment in Cyberinfrastructure Framework for the 21st Century Science and Engineering (CIF21); $22 million for cybersecurity activities; $60 million primarily to support a National Robotics Initiative; $12 million for basic research in radio spectrum systems; and $24 million in SDP for new software centers, CIF21, and increased SEES investment.

The Department of Energy request includes a $112 million (27 percent) increase: $66 million for research and new partnerships to address the challenges of emerging disruptive computing technologies from the private sector; $30 million for cybersecurity research; and $16 million for installation and operation of an Energy Sciences Network (ESnet) dedicated optical network.

The National Institute of Standards and Technology includes an increase of $53 million (65 percent), $25 million of which is to be used to support new cybersecurity

[10] Ibid., p. xiii.
[11] Ibid., p. 85.
[12] The Networking and Information Technology Research and Development Program Supplement to the President's FY 2012 Budget, p. 30.

initiatives. The remainder is spread across other PCAs for interoperability in emerging technologies activities.

Appendix A

H.R. 2020

The Networking and Information Technology Research and Development Act of 2009

SECTION-BY-SECTION ANALYSIS

Section 1. Short Title "Networking and Information Technology Research and Development Act of 2009."

Section 2. Program Planning and Coordination

Requires the NITRD agencies to periodically assess the program contents and funding levels and to update the program accordingly.

Requires the NITRD agencies to develop and periodically update (at three-year intervals) a strategic plan for the program. The characteristics and content of the strategic plan are described, and include strengthening NIT education, fostering technology transfer, and encouraging innovative, large-scale, and interdisciplinary research.

Encourages a more active role for OSTP in ensuring that the strategic plan is developed and executed effectively and that the objectives of the program are met.

Ensures that the existing advisory committee for NITRD is closely linked to the President's Council of Advisors on Science and Technology while retaining the necessary breadth and depth of expertise in NIT fields.

Specifies that the annual report now required for the NITRD program explicitly describes how the program activities planned and underway relate to the objectives specified in the strategic plan.

Specifies that the annual report now required for the NITRD program include a description of research areas supported in accordance with Section 3, including the same budget information as is required for the Program Component Areas.

Section 3. Large-Scale Research in Areas of National Importance

Authorizes NITRD agencies to support large-scale, long-term, interdisciplinary research with the potential to make significant contributions to society and U.S. economic competitiveness and to encourage collaboration between at least two agencies as well as cost-sharing from non-federal sources.

Characteristics of the projects supported include: collaborations among researchers in institutions of higher education and industry, and may involve nonprofit research institutions and federal laboratories; leveraging of federal investments through collaboration with related State initiatives, when possible; and plans for fostering technology transfer.

Authorizes support of activities under this section through interdisciplinary research centers that are organized to investigate basic research questions and carry out technology demonstration activities.

Section 4. Cyber-Physical Systems and Information Management

Requires the program to support research and development in cyber-physical systems; human-computer interactions, visualization, and information management.

Requires the NCO Director to convene a university/industry task force to explore mechanisms for carrying out collaborative research and development activities for cyber-physical systems with participants from universities, federal laboratories, and industry. The NCO is to report to Congress on any findings and recommendations from the task force on models for collaborative R&D.

Section 5. National Coordination Office

Formally establishes the NCO; delineates the office's responsibilities; mandates annual operating budgets; specifies the source of funding for the office (consistent with current practice); and stresses the role of the NCO in developing the strategic plan and in public outreach and communication with outside communities of interest.

Appendix B*

Agency NITRD Budgets by Program Component Area

FY 2010 Budget Actuals, *FY 2011 CR Levels,* and **FY 2012 Budget Requests**

(Dollars in Millions) *[Footnotes on next page]*

		High End Computing Infrastructure & Applications	High End Computing Research & Development	Cyber Security & Information Assurance	Human-Computer Interaction & Information Management	Large Scale Networking	High Confidence Software & Systems	Software Design & Productivity	Social, Economic, & Workforce Implications of IT	
Agency		**(HEC I&A)**	**(HEC R&D)**	**(CSIA)**	**(HCI &IM)**	**(LSN)**	**(HCSS)**	**(SDP)**	**(SEW)**	**Total [1]**
NSF	2010 Actual	325.2	89.1	72.7	269.8	121.0	74.3	54.4	99.2	1,105.6
	2011 CR Level [2]	*310.9*	*98.5*	*71.4*	*280.7*	*107.2*	*73.1*	*57.6*	*91.2*	*1,090.5*
	2012 Request	**308.1**	**123.8**	**94.7**	**330.0**	**132.6**	**91.8**	**78.8**	**98.0**	**1,257.7**
NIH [3]		309.0	18.0	0.1	213.0	17.0	8.0	46.0	35.0	646.1
		309.0	*18.0*	*0.1*	*213.0*	*17.0*	*8.0*	*46.0*	*35.0*	*646.1*
		316.0	**18.0**	**0.1**	**213.0**	**17.0**	**8.0**	**46.0**	**35.0**	**653.1**
OSD and DoD Service research orgs. [4]		257.6	19.4	89.5	99.5	105.8	34.3	19.6		625.8
		251.2	*21.3*	*85.6*	*93.8*	*110.3*	*24.3*	*19.4*		*605.8*
		189.9	**9.4**	**72.3**	**103.4**	**95.4**	**23.8**	**17.7**		**511.8**
DOE [5]		276.7	87.8	3.5		44.4			6.0	418.4
		282.5	*81.6*	*33.5*		*53.6*			*6.0*	*457.2*
		332.6	**98.2**	**33.5**		**59.6**			**6.0**	**529.9**
DARPA			116.0	144.7	173.9	96.3				531.0
			121.2	*119.1*	*150.8*	*75.1*	*5.0*			*471.3*
			56.9	**222.4**	**136.7**	**54.2**	**10.0**			**480.2**
NIST		17.0	3.6	29.6	14.1	6.2	4.7	5.5	0.3	81.0
		17.0	*3.6*	*29.6*	*14.1*	*6.2*	*4.7*	*5.5*	*0.3*	*81.0*
		17.0	**4.4**	**54.7**	**18.8**	**14.2**	**10.4**	**10.1**	**4.3**	**133.9**
NASA		59.4	0.8		16.0	0.8	5.8	2.5		85.3
		61.4	*0.5*		*12.5*	*0.8*	*4.8*	*2.4*		*82.3*
		62.2	**0.5**		**10.0**	**0.8**	**13.2**	**8.0**		**94.7**
NSA			118.4	29.0		2.8	5.6			155.8
			31.0	*30.0*		*3.5*	*7.6*			*72.1*
			19.5	**29.2**		**4.2**	**6.8**			**59.7**
DHS				38.0	3.9	8.0				49.9
				37.0	*4.2*	*9.0*				*50.2*
				41.0	**5.4**	**10.0**		**0.7**		**57.1**
AHRQ					27.1	0.5				27.6
					27.1	*0.5*				*27.6*
					27.1	**0.5**				**27.6**
NOAA		23.4	0.2		0.5	1.5		0.7		26.3
		20.9	*0.2*		*0.5*	*4.0*		*0.7*		*26.3*
		20.9	**0.2**		**0.5**	**4.0**		**0.7**		**26.3**
DOE/NNSA		8.9	16.1			0.9			3.7	29.6
		10.3	*14.7*			*1.2*			*4.1*	*30.3*
		9.5	**11.5**			**0.9**			**4.0**	**25.9**
EPA		3.3			3.0					6.3
		3.3			*3.0*					*6.3*
		2.9			**3.0**					**5.9**
NARA					4.5					4.5
					4.5					4.5
					2.5					**2.5**
TOTAL (2010 Actual) [1]		1,280.5	469.4	407.1	825.4	405.2	132.7	128.7	144.2	3,793
TOTAL (2011 CR Level) [1]		*1,266.4*	*390.6*	*406.3*	*804.2*	*388.3*	*127.5*	*131.6*	*136.6*	*3,652*
TOTAL (2012 Request) [1]		**1,259.1**	**342.3**	**547.9**	**850.4**	**393.4**	**163.9**	**161.9**	**147.3**	**3,866**

*The Networking and Information Technology Research and Development Program Supplement to the President's FY 2012 Budget, p. 28

Chairman BROOKS. The Subcommittee on Research and Science Education will come to order. Good afternoon. As a very quick preamble, we are expecting votes at any point in time. If we are called for votes, we will have to break temporarily until such point as the votes are concluded and then if it is all right with you, Congressman Lipinski, be back five minutes after the last vote? We will try to reconvene then five minutes after the last vote.

That out of the way, welcome to today's hearing entitled "Oversight of the Networking and Information Technology Research and Development Program and Priorities for the Future." Today we are presented with the opportunity to review the Networking and Information Technology Research and Development Program, abbreviated NITRD, and to discuss priorities for the future.

The NITRD Program is the main federal research and development investment portfolio in unclassified networking, computing, software, cybersecurity, and related information technologies. It also serves as the mechanism for interagency coordination of this research and development. Fourteen member agencies, including the National Science Foundation, National Aeronautics and Space Administration, the Department of Energy, NOAA, and the Department of Homeland Security provide budgets for NIT research and development. Numerous other agencies are also actively engaged in the coordination.

Networking and information technology includes an array of technologies from smart phones to cloud computing. Multidisciplinary innovations include computational decoding of the human genome, modeling and simulation of complex physical systems for aircraft, automobiles, power grids and pharmaceuticals, near-real-time weather forecasts and climate models, and unmanned aerial vehicles and search-and-rescue robots. Among its many goals, NIT research and development in this field works to minimize and prevent disruptions to critical infrastructures like power grids and emergency communication systems. These investments are necessary not only to help maintain world leadership in science and engineering and strengthen U.S. competitiveness, but they also grow the economy through the creation of NIT jobs and enhance national security.

For instance, cybersecurity is one of the biggest security challenges facing our Nation today. It permeates through all of our federal agencies and even into our private computer systems. This is just one area that the NITRD Program helps to coordinate our federal research and development. It indicates how imperative it is that we continue to support critical and collaborative research efforts such as this.

Today, our witnesses will share with us their insights on the current state of the program and future priorities. It has been several years since the NITRD program was last reviewed by this Subcommittee. The program was reauthorized by the House in the last Congress on two occasions, only to languish in the Senate. Hopefully, input from our experts today will help inform this subcommittee's current work and bring to light new advances and challenges for the NIT R&D since the last bill's introduction.

Part of this Subcommittee's role is to ensure that federal dollars are being spent on the best research and development. At a time when American competitiveness and national security are at risk, it is important that we maintain our lead in the development of these crucial technologies.

I look forward to hearing from each of our witnesses on this important topic. Thank you for joining us.

[The prepared statement of Mr. Brooks follows:]

PREPARED STATEMENT OF CHAIRMAN MO BROOKS

Good morning, and welcome to each of our witnesses. Today, we are presented with the opportunity to review the Networking and Information Technology Research and Development Program (NITRD) and to discuss priorities for the future.

The NITRD program is the main federal R&D investment portfolio in unclassified networking, computing, software, cybersecurity, and related information technologies. It also serves as the mechanism for interagency coordination of this R&D. Fourteen member agencies, including the National Science Foundation, NASA, the Department of Energy, NOAA, and the Department of Homeland Security provide budgets for NIT research and development. Numerous other federal agencies are also actively engaged in the coordination.

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Chairman BROOKS. At this time I defer to the Ranking Member on the Democrat side, Mr. Lipinski, for his remarks.

Mr. LIPINSKI. Thank you, Chairman Brooks. As the Chairman noted it has been more than two years since this Committee developed and passed bipartisan legislation to reauthorize and update the NITRD Program. I was a co-sponsor of Chairman Gordon's bill in 2009, and as the Chairman said, the Senate never acted on it, of course, that is not the first time it has been said in this Subcommittee. It seems like almost every hearing. I am hoping that this hearing is the first step towards action in this Congress.

Networking and information technologies are developing quickly. In the last two years not only has the NIT landscape changed but a committee of experts, PCAST, has delivered a new set of recommendations and priorities to Congress. The previous PCAST report was very helpful in developing our last bill, so I am looking forward to hearing from the witnesses about what has changed in the last two years and how that bill can be updated and improved.

The NITRD Program evolved from a federal program established under the High Performance Computing Act of 1991. That act provided the funding that led to the development of Mosaic in 1993, the Worldwide 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 Super Computing Applications at the University of Illinois.

Netscape founder Mark Andreesen, who was the leader of the Illinois team before launching his own company, was quoted as saying, "If it had been left to private industry, it wouldn't have happened. At least not until years later."

It was an unfortunately worded reference to the High-Performance Computing Act of 1991, by its author and champion Al Gore, which turned into the punch line that Al Gore invented the Internet. But it is without question that the act did set the stage for coordinated federal R&D and investment strategy that has underpinned U.S. leadership in networking and information technology over the past two decades.

Today we find ourselves in a different world in which U.S. leadership in NIT can no longer be taken for granted, and we need to think carefully about how we set priorities under difficult budget conditions. PCAST recommended three areas for priority investments; NIT for health, NIT for energy and transportation, and cybersecurity. This third area, cybersecurity, has been one of my highest priorities this Congress, and I joined Mr. McCaul in introducing the Cybersecurity Enhancement Act earlier this year.

I look forward to hearing from witnesses about priorities and future directions of NITRD's cybersecurity component.

Finally, I want to say a few words about NIT education and workforce issues. In 2009, SRI International produced a report on NIT workforce at the request of the NITRD Program office. In that report the analysts at SRI found that the NIT landscape is more complicated than just the "more jobs than skilled workers" mantra we sometimes hear. The supply and demand curve really depends on the sector within NIT and the level of education skills that we are talking about. I watch with growing concern as some of our leading IT companies have outsourced increasing numbers of jobs, following a disturbing pattern that has decimated manufacturing in our country.

Over the past decade since, IBM's domestic workforce has suddenly shrunk while its overseas workforce has grown. As of last year it was down to one-quarter of the total, and for the first time ever, the company stopped providing breakouts of the number of employees that it has in the U.S. While the company's Project Match Program is offered to help workers laid off from domestic sites obtain travel and visa assistance for jobs in countries like India, China, and Brazil, and even though IBM has withdrawn its patent application for a *"Method and System for Strategic Global Resource Sourcing,"* I am worried that we could be training students for jobs that end up having the jobs being outsourced.

At the same time I know that we have a real need for cybersecurity professionals who can help protect our most sensitive networks, informaticians who can discover new ways to deal with the exponentially growing amount of data we produce.

So I want to hear from the witnesses today about how we can be confident we are training students for jobs that will be available here in the U.S. and how we can focus education and training resources within NITRD on those job skills.

I thank the witnesses again for taking the time to appear before us and to help educate us about the NITRD Program, and I look forward to your testimony.

Thank you.

[The prepared statement of Mr. Lipinski follows:]

PREPARED STATEMENT OF RANKING MEMBER DANIEL LIPINSKI

Thank you, Chairman Brooks. [As the Chairman noted] It has been more than two years since this Committee developed and passed bipartisan legislation to reauthorize and update the NITRD program. I was a cosponsor of Chairman Gordon's bill in 2009, and while the Senate never acted on it, I hope that this hearing is the first step towards action in this Congress.

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I have watched with growing concern as some of our leading IT companies have outsourced increasing numbers of jobs, following the disturbing pattern that has decimated manufacturing in this country. Over the past decade, for instance, IBM's domestic workforce has steadily shrunk while its overseas workforce has grown. As of last year it was down to one quarter of the total, and for the first time ever the company stopped providing breakouts of the number of employees it has in the U.S.

While the company's "Project Match" program has offered to help workers laid off from domestic sites obtain travel and visa assistance for jobs in countries like India, China, and Brazil, and even though IBM has withdrawn its patent application for a *"Method and System for Strategic Global Resource Sourcing,"* I worry that we could be training students for jobs that end up being outsourced. At the same time, I know that we have a real need for cybersecurity professionals who can help protect our most sensitive networks and informaticians who can discover new ways to deal with the exponentially growing amount of data we produce.So I want to hear from the witnesses today about how we can be confident we are training students for jobs that will be available here in the U.S., and how we can focus education and training resources within NITRD on those job skills. Thank you again for taking the time to appear before us today to help educate us about the NITRD program, and I look forward to your testimony.

Chairman BROOKS. 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 for today's panel. First we have Dr. George Strawn. He is the director of the National Coordination Office for the Networking and Information Technology Research and Development Program. Prior to his appointment as Director of NITRD Dr. Strawn served as the Chief Information Officer at the National Science Foundation. Dr. Strawn holds a Bachelor of Arts in mathematics and physics from Cornell College and a Doctorate in mathematics from Iowa State University.

Next we have Dr. Edward Lazowska. He holds the Bill and Melinda Gates Chair in Computer Science and Engineering at the University of Washington and is the Founding Director of the University of Washington eScience Institute. He also serves as a board member or technical advisor to a number of high-tech companies and venture firms. Dr. Lazowska holds a Bachelor of Arts from Brown University and a Doctorate from the University of Toronto.

Dr. Robert Sproull recently retired as Vice President, Director of Oracle Labs. He is a member of the National Academy of Engineering, a Fellow of the American Academy of Arts and Sciences, and had served on the United States Air Force Scientific Advisory Board. Dr. Sproull holds a Bachelor of Arts in physics from Harvard and a Doctorate in computer sciences from Stanford.

Dr. Robert Schnabel is the Dean of the School of Informatics at Indiana University. From August 2009 to July 2010, he served as Interim Vice President for Research for Indiana University. Dr. Schnabel holds a Bachelor of Arts in mathematics from Dartmouth College and a Master of Science and a Doctorate from Cornell University, both in computer science.

As our witnesses should know, spoken testimony is limited to five minutes, after which the Members of the Committee will have five minutes each to ask questions.

At this point I recognize our first witness, Dr. George Strawn. Dr. Strawn, you are recognized for five minutes.

STATEMENT OF DR. GEORGE STRAWN, DIRECTOR, NATIONAL COORDINATION OFFICE, NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT PROGRAM

Dr. STRAWN. Good afternoon. As you have noted, I am George Strawn, the Director of the National Coordination Office for the NITRD Program, and along with Farnam, Dr. Farnam Jahanian of NSF, I also co-chair the NITRD Interagency Committee. I would like to thank Chairman Brooks, Ranking Member Lipinski, and

Members of the Subcommittee for the opportunity to discuss the role of the NITRD Program in helping the United States maintain its leadership in networking and information technology.

The NITRD Program provides for the coordination of the government's portfolio of unclassified investments in research and development in NIT. The National Coordination Office hosted at NSF facilitates the various activities of the NITRD Program. My written testimony describes NITRD in some detail, and I will now highlight three of the topics discussed there: first, some of our newest activities; second, why federal investment in NIT R&D remains crucial; and third, one of the reasons why NITRD collaboration is successful.

First, our newest NITRD activities include five new coordination groups, one in NIT education, a second in cybersecurity, and in fact, it is our second coordination group in cybersecurity, one in health IT, one in wireless spectrum efficiency, and one in what we are calling big data. Cybersecurity is important enough that this subcommittee held a separate hearing on it last May. Given my time limits I will just say a word about big data as one of our new activities.

Federal agencies in the NITRD Program are generating exabytes of research data annually. An exabyte is a billion, billion bytes, and society at large is generating a similar amount. Our ability to create and store data has greatly outpaced our ability to preserve, manage, access, and make effective use of it. The agencies participating in our big data group have identified four initial focus areas; core technologies research, big data projects, education and training for big data scientists, and competitions and prizes to stimulate general activity in the area.

I anticipate important advances in the science and practice of big data.

Next, the importance of federal NIT investments is illustrated by the many federally-supported projects that helped spawn the information age, going all the way back to the 19th century. The U.S. Congress supported Samuel F.B. Morse's development of the telegraph, for example. The U.S. Census Bureau supported the development of an innovative punch-card technology to store and process census data, which became the IBM Corporation. More recent examples include the U.S. Army's development of the electronic digital computer, DARPA's development of the ARPAnet followed by NSF's development of the NSFnet, followed by the Internet industry. And as previously mentioned, NSF's support for the research that led to the first Web browser and then to the Google search engine.

The multiplier effects of federal NIT R&D investments is widely documented, perhaps most famously in the National Research Council's tire tracks diagram, which shows the interplay of federal and private sector investments that has turned many NIT research projects into billion dollar markets.

Finally, one reason for the effectiveness of NITRD collaboration model is that it involves both mission agencies and agencies who are focused on the use of IT and agencies focused on the theory of IT. As political scientist Donald Stokes showed in his 1997 book, "Pasteur's Quadrant," R&D is better described as a two-dimensional activity rather than the usual linear description where research always precedes development.

His dimensions were use value and theory value, and his point was high-use value can be concurrent with or even occasionally precede high-theory value. For example, the Army's need for and development of the digital computer preceded the development of most computing science theory. NIT R&D can be especially fruitful when high use and high-theory value are brought together, and that is exactly what the NITRD Program seeks to accomplish.

Thank you, again, for the opportunity to provide this testimony, and I would be happy to answer any questions you may have.

[The prepared statement of Mr. Strawn follows:]

PREPARED STATEMENT OF DR. GEORGE STRAWN,
DIRECTOR, NATIONAL COORDINATION OFFICE,
NETWORKING AND INFORMATION TECHNOLOGY RESEARCH AND DEVELOPMENT PROGRAM

I am George Strawn, Director of the National Coordination Office (NCO) for the Networking and Information Technology Research and Development Program (NITRD). With my colleague, Dr. Farnam Jahanian of the National Science Foundation (NSF), I co-chair the NITRD Subcommittee of the National Science and Technology Council's Committee on Technology. I want to thank Chairman Brooks, Ranking Member Lipinski, and Members of the Subcommittee for the opportunity to come before you today to discuss the role of the NITRD Program in helping the United States maintain leadership in networking and information technology (NIT).

Prior to coming to the NCO for NITRD in 2009, I was at the National Science Foundation (NSF) and had taken part in NITRD activities as an NSF staff member since 1995. The positive impression I formed about NITRD during those years led me to apply for my current position and adds to my appreciation of this opportunity to testify before you today.

NITRD Overview

The NITRD Program has been authorized under three legislative acts. The first, the High Performance Computing Act of 1991 (Public Law 102–194), established the Program, setting forth a framework that combined research goals with specific provisions for interagency cooperation, collaboration, and partnerships with industry and academia. Two additional acts— the Next Generation Internet Research Act of 1998 (Public Law 105–305) and the America COMPETES Act of 2007 (Public Law 110–69)—reauthorized the Program and extended its scope in various ways.

As the NITRD Program this year celebrates its 20th anniversary, I hope the Members of this Subcommittee and its parent Committee share the NITRD community's pride that our multi-agency framework has truly met the test of time. Over the course of two decades, the authorizing legislation has enabled the NITRD enterprise to evolve and expand to address increasingly rapid technological shifts and new responsibilities.

The framework of the NITRD Program provides for coordination across the government's portfolio of unclassified investments in fundamental, long-term research and development (R&D) in advanced networking and information technology (NIT). NITRD research supports both the missions of our federal agencies and the Nation's broader goals such as homeland and national security, economic competitiveness, energy independence, environmental stewardship, affordable health care, and science and engineering leadership.

All of the research reported in the NITRD portfolio is managed, selected, and funded by one or more of the 18 NITRD member agencies (listed on page 14) under their own individual authorizations and appropriations. The Program's major research areas (termed Program Component Areas [PCAs] in the 1998 reauthorization legislation) currently include:

- 1. Cyber security and information assurance;
- 2. High-confidence software and systems;
- 3. High-end computing;
- 4. Human-computer interaction and information management;

- 5. Large-scale networking;
- 6. Social, economic, workforce implications of IT and workforce development;
- 7. Software design and productivity.

We have also launched some exciting new ventures that are highlighted below.

NITRD research is performed in universities, federal research centers and laboratories, federally funded R&D centers, private companies, and nonprofit organizations across the country. The synergy exhibited by the NITRD member and participating agencies (listed on page 15)—is accomplished through interaction across the government, academic, commercial, and international sectors using cooperation, coordination, information sharing, and joint planning. Collaborative activities are focused on selected areas where the agencies can identify technical challenges that multiple agencies face and address them together to leverage each other's activities. These targeted collaborations enable the agencies to maximize resource sharing, minimize duplication of effort, and partner in investments to pursue higher-level goals.

Structure of NITRD Coordination

The Subcommittee on Networking and Information Technology Research and Development of the National Science and Technology Council's (NSTC) Committee on Technology (CoT) serves as the internal deliberative organization for NITRD policy, program, and budget guidance and direction within the Executive Branch. The NITRD Subcommittee interacts with federal agencies that need advanced networking or information technology to identify networking and information technology research and development needs. Its high-level goals are to help assure continued U.S. leadership in networking and IT, satisfy the needs of the federal government for advanced IT capabilities, and accelerate development and deployment of new technologies. Subcommittee members include senior R&D managers from each of the member agencies and representatives from the Office of Management and Budget (OMB), Office of Science and Technology Policy (OSTP), and the NCO. The Subcommittee interacts with Congress, OMB, OSTP, the NSTC, the CoT, other Federal agencies, and private-sector and international organizations on behalf of the NITRD Program.

The NCO facilitates the activities of the NITRD Program (see list immediately below), and the office serves as the hub of public information about the Program. The NCO's technical, administrative, NIT services, and administrative support staff provide program and financial management services; technical and subject-matter expertise in facilitation, strategic planning, technical writing, networking and IT services; and administrative staff support for the NITRD Subcommittee and the IWGs, CGs, SSGs, Teams, and other NITRD subgroups. The cost of operating the NCO is shared by the NITRD member agencies in proportion to their NITRD budgets. The NCO also supports the President's Council of Advisors on Science and Technology (PCAST), under Executive Order 13539. The NCO Director reports to OSTP, works closely with OSTP and OMB, and attends OSTP technical-staff meetings. NSF serves as the host agency for the NCO. The NCO maintains the NITRD Web site (*www.nitrd.gov*) and prepares and archives NITRD publications.

Supported by the NCO's staff and services, the NITRD Program uses the following general mechanisms to pursue its coordination mission:

- Monthly meetings of its Interagency Working Groups (IWGs), Senior Steering Groups (SSGs), Coordinating Groups (CGs), Teams, and Subgroups (SGs). These regular interactions among representatives from many agencies enable participants to exchange information and collaborate on research plans and activities such as standards development, testbeds, research workshops, cooperative solicitations, and sharing operational best practices for federal NIT, such as in the annual DOE High Performance Computing (HPC) Best Practices Workshop.[1] Also as a result of these exchanges, NITRD representatives frequently serve on grant review panels and participate in principal investigator meetings of other agencies.
- Formation of new coordination activities as needed to address national priorities. These are described under "New NITRD Ventures" below.
- Workshops, which typically include academic and industry participants from across the country as well as federal representatives.

[1] *http://www.nersc.gov/events/hpc-workshops/*

- Formal reports, including the annual NITRD Supplement to the President's Budget, strategic planning documents, and workshop reports. These documents all play an important role in helping set national agendas in research areas of critical interest.
- Support for external studies and assessments.
- Outreach to the federal and private sectors.

New NITRD Ventures

Cybersecurity SSG

In 2008, as part of a mandate to improve coordination of federal cybersecurity R&D under the Comprehensive National Cybersecurity Initiative (CNCI), the NITRD agencies developed a plan calling for the establishment of a new kind of coordinating group under NITRD. An interagency Senior Steering Group (SSG) for cybersecurity R&D was established whose members included federal managers with budgetary responsibilities. This group was in addition to our cybersecurity PCA. A key goal of the SSG concept was to facilitate moving strategic cybersecurity R&D approaches developed by the NITRD agencies into programmatic activities. The Cybersecurity SSG has proven effective and we have adopted the same model to establish other NITRD SSGs.

Like the Cybersecurity SSG, the new SSGs enable NITRD to broaden its focus from established NIT R&D categories to ones that address new opportunities and critical national priorities for the United States. These SSGs, and a new venture in the education arena, are described in the following sections. The participating agencies for each of the SSGs can be found on pages 16–17.

Big Data SSG

Most of the world's information is now "born digital," and legacy texts, images, sounds, videos, and films as well are being digitized around the clock. Typical estimates put the amount of digital data generated annually at many orders of magnitude greater than the total amount of information in all the books ever written, and the total is expected to continue growing exponentially. In the sciences alone—a central concern of our federal science agencies —the proliferation of ultra-powerful and distributed data-collection instruments and experimental facilities has turned the conduct of leading-edge research into a global-scale, data-intensive enterprise. Together, the federal agencies in the NITRD Program generate exabytes of research data annually. Financial, commercial, communications, and Web-based enterprises likewise generate vast amounts of new digital information on a moment-by-moment basis. However, our capacity to create electronic data is outpacing advances in the technologies needed to enable us to preserve, manage, access, and make effective use of society's data resources—the highly complex, ultra-large-scale data sets that we in NITRD refer to as "big data."

NITRD has a PCA for human-computer interaction and information management, but big data offers new possibilities and new challenges. Responding to a request from OSTP, NITRD formed the Big Data Senior Steering Group in January 2011. The Big Data SSG is charged with identifying current big data R&D activities across the Federal Government, offering opportunities for coordination and collaboration, and considering what national initiatives on big data would be most useful. The science of big data begins with issues of scale, complexity, and heterogeneity encompasses the many significant challenges in turning data into knowledge, including search, discovery, mining and visualization of ultra-scale data; interoperability; and semantics. In their first months, the agencies participating in the Big Data SSG have identified four focus areas for their initial activities: core technologies, data projects, training, and competitions.

Health IT R&D SSG

The formation of NITRD's Health IT R&D SSG is our response to the American Recovery and Reinvestment Act of 2009 (Public Law 111–5), which called on NITRD to "have programs in Health IT R&D." We have always had mission agency members, but this is the first time that a formal NITRD activity is devoted to a mission programmatic goal—improving health and health care. Health IT R&D includes fundamental research, applied R&D, technology development and engineering, demonstrations, testing and evaluation, technology transfer, and education and training.

The Health IT R&D SSG was launched in January 2010 after an initial NITRD planning activity on the topic. The agencies participating in the group are working towards a next-generation health information infrastructure that will provide universal, interoperable information systems for U.S. health care. R&D challenges include, to name just a few: universal data exchange language; security, privacy, and identity management; interoperable electronic health records (EHRs); personal health records (PHRs); devices/sensors; and further empowering of "e-patients." The SSG's interests also encompass: coordination of standards, implementation specifications, and certification criteria; maintaining frequent communication with, and serving as the liaison among, the SSG agencies, academia, and industry; and responding to U.S. national goals for health IT R&D and the health IT recommendations of PCAST in its 2010 report *Realizing the Full Potential of Health Information Technology to Improve Healthcare for Americans: The Path Forward.*[2]

The Health IT R&D SSG is developing a health information technology recommendations document that provides research directions for health IT R&D. In addition, the SSG has formed the Health Information Technology Innovation and Development Environments (HITIDE) subgroup, which is working on policy and governance issues for experimental testbed activities. Testbeds will enable our agencies to try out new health technology prototypes in realistic, real-time environments.

Wireless Spectrum R&D (WSRD) SSG

The Wireless Spectrum R&D SSG was established in November 2010 to coordinate spectrum-related research and development activities across the Federal Government. WSRD's purpose is: to help coordinate and inform ongoing activities across federal agencies; and to facilitate the identification of gaps in the government's R&D portfolio with respect to technologies that allow a more efficient use of spectrum. These activities are consistent with the guiding principles of WSRD, which are transparency, smart investment, and the expansion of opportunities for technology transfer across and beyond the Federal Government.

The WSRD members have developed a preliminary inventory of some 670 federal wireless spectrum R&D activities and are preparing a gap analysis from the inventory and recommendations on federal research that could advance the goals of the June 28, 2010, Presidential Memorandum: "Unleashing the Wireless Broadband Revolution," Section 3. In addition, WSRD will work with academia and the private sector to develop priorities, encourage private investment, and develop public/private partnerships when appropriate.

Cyber-Physical Systems

H.R. 2020 calls out cyber-physical systems (CPS) as a new area of national priority for NITRD activity. Cyber-physical systems are real-time, networked computing systems—interconnected software, microprocessors, sensors, and actuators—deeply integrated within engineered physical systems to monitor and control capabilities and behaviors of the physical system as a whole. Such systems have become increasingly important to our society and are essential to the effective operation of: U.S. defense and intelligence systems; critical civilian infrastructures (e.g., air traffic control, power grid, and water supply systems), industrial-process control systems, and other large-scale civilian systems; as well as to smaller-scale systems that are vital for U.S. economic competitiveness (e.g., in airplanes, cars, robotic devices, and medical instruments and devices).

Much of the work of NITRD's High Confidence Software and Systems (HCSS) PCA over the past decade has been focused on CPS research and building a national CPS research community that engages multiple sectors and disciplines. Currently, we are considering augmenting this work with an SSG devoted specifically to CPS R&D. In addition to H.R. 2020, the last two PCAST reviews of our Program (*Leadership Under Challenge: Information Technology R&D in a Competitive World,*[3] August 2007, and *Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology,*[4] December 2010) concluded that improving the quality, capabilities, and trustworthiness of our life- and safety-critical information technologies, including cyber-physical systems, should be a key focus of federal research.

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[2] *http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-health-it-report.pdf*
[3] *http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-07-nitrd-review.pdf*
[4] *http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nitrd-report-2010.pdf*

Education and Workforce Activities

As employers with needs for all kinds of highly skilled scientific and technical NIT personnel, the NITRD agencies are acutely aware of some of the problems in our formal education system that limit the number of graduates adequately prepared to become part of the NIT workforce. To underscore their concern, in the draft strategic plan for NITRD the agencies highlight development of a "cyber-capable" U.S. population as one of three critical foundations for a bright national future. One immediate outcome of the strategic planning discussions has been the establishment of a new Team (called SEW-Education) under the auspices of NITRD's Social, Economic, and Workforce Implications of IT and IT Workforce Development (SEW) Program Component Area.

The SEW-Education team is seeking ways to promote the integration of instruction about the science of computing throughout the K–12 curriculum. Indeed, the former co-Chair of the NITRD Subcommittee, Dr. Jeannette Wing (now back at the computer science department at Carnegie-Mellon University), introduced the concept of "computational thinking for everyone." She spearheaded NSF initiatives to support development of innovative ways to familiarize students at all levels with the fundamental concepts of computation, such as algorithms, and how they can be applied to solve problems in every domain—just as students now learn fundamental concepts in mathematics and other sciences in grade-appropriate curricula starting at the elementary level.

In national public forums we held in 2008 and 2009 to inform NITRD strategic planning, academic computer scientists and K–12 educators told us that few, if any, K–12 schools had a curriculum in computer science (CS). According to these experts, computer science teaching was limited to an introductory high school course in programming, offered by only 65 percent of high schools in 2009 and taken by a small percentage of students. In lower grades, they said, teachers informally helped students use computer applications but there was virtually no instruction about the science of computation. In a society increasingly dependent on complex digital systems, the NITRD agencies believe, the gaps in K–12 students' knowledge and experience, and in the availability of skilled CS teachers, are worrisome and need to be addressed through grade-appropriate computer science curricula.

At the same time, the demand for NIT workers is growing. A 2009 study conducted for NITRD by SRI otes that two NIT-related occupations—network systems and data communications analyst, and computer applications software engineer—are among the five fastest-growing in the U.S. economy, and are the only two of the five to require a college degree. 1A[5] According to U.S. Bureau of Labor Statistics projections in 2010, there were 7.6 million STEM workers in the United States, representing about one in 18 workers. STEM occupations are projected to grow by 17.0 percent from 2008 to 2018, compared to 9.8 percent growth for non-STEM occupations. STEM workers command high wages, earning 26 percent more than their non-STEM counterparts, more than two-thirds of STEM workers have a least a college degree, compared to less than one-third of the non-STEM workers, and STEM degree holders enjoy high earnings, regardless of whether they work in STEM or non-STEM occupations.

Furthermore, labor-market projections for the NIT workforce do not capture the reality that a very broad range of occupations increasingly involves applications that require NIT knowledge and skills. Nor can statistical projections serve as a guide for assessing the adequacy of the educational system to prepare a workforce that leads the world in advanced innovation. The managers of the NSF programs targeting the K–12 problem participate in the SEW-Education group and are helping develop its action plan. The first NSF effort, Computing Education for the 21st Century (CE21), is focusing special attention on the middle school through early college levels, with the goals of: increasing the number and diversity of students and teachers who develop and practice computational competencies in a variety of contexts; and increasing the number and diversity of postsecondary students who are engaged and have the background in computing necessary to successfully pursue degrees in computing-related and computationally intensive fields of study. [6]

The second NSF activity, CS 10K (which stands for 10,000 Computer Science teachers in 10,000 high schools), aims to increase the effectiveness of computing education in high school through the introduction of an entirely new curriculum

[5] Commissioned by the NITRD Subcommittee in response to Recommendation 2.1 (page 23) of *Leadership Under Challenge*, the 2007 PCAST report on its review of the NITRD Program.
[6] *http://www.nsf.gov/funding/pgm_summ.jsp?pims_id=503582*

(based on a proposed, new Advanced Placement course) concomitant with the preparation of teachers prepared to teach it by 2015.[7]

A three-year, $14.2 million effort initiated in 2010 by SEW-Education participant and NITRD member DARPA is also directed to the middle- and high-school levels of the K–12 system. Citing the decline in CS college graduates and the growing need for computer scientists and engineers, the agency's solicitation asked for innovative proposals to: combat young people's misperception that the "dot.com" bust eliminated all CS jobs; excite middle- and high-school students about CS and STEM careers; provide means of retaining the excitement of extracurricular activities, such as NASA's Space Camp, in the regular curriculum; and offer plans for institutionalizing the new approaches over the long term.[8]

These efforts are complemented by the National Initiative for Cybersecurity Education (NICE) led by NIST. This comprehensive program, to which many NITRD agencies are contributing, includes activities in four component areas: national cybersecurity awareness; formal cybersecurity education; cybersecurity workforce structure; and cybersecurity workforce training and professional development.[9]

SEW-Education also plans to coordinate its efforts with those of the new NSTC Committee on Science, Technology, Engineering, and Math Education (CoSTEM). The COMPETES Act of 2010 directed OSTP to set up this committee, which is cochaired by OSTP and NSF, and gave it the following responsibilities:

- Coordinate the STEM education activities and programs of the federal agencies;
- Coordinate STEM education activities and programs with the Office of Management and Budget;
- Encourage the teaching of innovation and entrepreneurship as part of STEM education activities;
- Review STEM education activities and programs to ensure they are not duplicative of similar efforts within the federal government;
- Develop, implement through the participating agencies, and update once every five years a five-year STEM education strategic plan.

Other Recent NITRD Highlights

In addition to the recent NITRD developments described above, I am pleased to report that we have welcomed four new agencies as members of the NITRD Program. Last spring, the Office of the National Coordinator (ONC) for Health Information Technology of the Department of Health and Human Services became a NITRD member. The ONC representative also serves as a co-chair of the Health IT R&D Senior Steering Group. We are also delighted that the Department of Defense's Service research organizations—the Air Force Research Laboratory (AFRL), the Army Research Laboratory (ARL), and the Office of Naval Research (ONR) have come onboard as NITRD member agencies. The Service labs have long been active participants in the Program's research groups, so it is gratifying to have the benefit of their contributions as Subcommittee members as well.

I want also to note briefly that the National Coordination Office is working on a prototype R&D dashboard that will provide greater access to NITRD funding data, enabling the public to explore the Program's research activities in greater depth. You can find our initial conceptual dashboard on the NITRD Web site.[10]

Maintaining U.S. Leadership in Networking and Information Technology

Networking and information technology—computers, wired and wireless digital networks, electronic data and information, IT devices and systems, and software applications—today provide the indispensable infrastructure for activities across all facets of our society and our economy. Throughout the IT revolution, the United States has led the world in the invention and applications of these technologies. For well over six decades, ongoing federal research and development to supply advanced IT capabilities for government missions has fueled the creation of new ideas, innovators, and innovations addressing key national priorities, such as those cited above and repeated here for emphasis: homeland and national security, economic

[7] *http://www.computingportal.org/cs10k*

[8] *http://www.darpa.mil/Our_Work/I2O/Programs/Computer_Science_in_Science_Technology_Engineering_and_Mathematics_Education_(CS-STEM).aspx*

[9] *http://csrc.nist.gov/nice/*

[10] *http://itdashboard.nitrd.gov/*

competitiveness, energy independence, environmental stewardship, affordable health care, and science and engineering leadership. In fact, the 2010 PCAST review of NITRD noted that "the federal investment in NIT research and development is without question one of the best investments our Nation has ever made."

There is no doubt that the historic U.S. supremacy in NIT is under global challenge from aggressive competitors. We no longer manufacture all the components for the NIT products we use, and that pipeline is something we need to monitor carefully. However, we need to be mindful that the U.S. companies that so successfully built our country's multibillion-dollar NIT commercial marketplace are also becoming global enterprises. I believe that we remain the world's NIT leader, but continued innovation leadership is required to maintain our position.

I come to the NIT leadership question with the perspective of a computer scientist who has for many years been a student of the history of U.S. information technologies. Technology innovation proceeds in extended cycles. Big—usually unexpected—scientific discoveries come first, followed by long periods of incremental innovations and commercialization of products developed out of the initial fundamental advances. In the field of networking and information technology in particular, the Federal Government has historically been the sponsor of the fundamental scientific breakthroughs that spawned the information revolution. This history dates back to the 1800s. In the 1830s, the U.S. government supported Samuel F.B. Morse's development of the telegraph. In the 1890s, the U.S. Census Bureau supported the work of its employee, Herman Hollerith, in developing an innovative punch-card technology to record and store census data. Several decades later, the company Hollerith subsequently started became the International Business Machines Corporation (IBM). More recent examples include the Army-supported development of the electronic computer; DARPA's support for the ARPAnet followed by NSF's support for the NSFnet, which became the Internet; and NSF's support for the research that brought us the first Web browser and the Google Web search engine.

The NITRD Program sustains this historic federal role in discovery, in the 21st century's far more complicated global technological and economic environment. As noted above, our collaborative multi-agency framework has enabled the NITRD agencies to keep evolving their NIT activities to keep pace with the increasing pace of emerging technologies and applications. The portfolio of research and development activities sponsored by the NITRD agencies grows ever broader. I would argue that this portfolio is an invaluable resource for maintaining U.S. leadership in NIT because it is the Nation's only full-spectrum NIT R&D enterprise.

Thus the NITRD portfolio serves a unique purpose in what many term "the U.S. innovation ecosystem." Over the decades, the United States has developed a fluid, information-rich research and innovation environment that stretches from federal programs and laboratories, across university campuses and research centers, to industrial R&D facilities and small business start-ups. As the National Academies and others have noted,[11] there are innumerable feedback loops in this ecosystem through which ideas and concepts travel, get transformed, fuel new directions, turn student experimenters into skilled technologists and keen entrepreneurs, and ultimately produce path-breaking innovations. The NITRD research performed in universities, federal research centers and laboratories, federally funded R&D centers, and in partnerships with private companies and nonprofit organizations across the country generates continuous interaction, information exchange, and feedback in the ecosystem, providing new perspectives and insights to both federal and private-sector stakeholders. Through its broad reach across the ecosystem, NITRD funding also supports the education and training of the Nation's next generations of NIT researchers, technical experts, entrepreneurs, and IT industry leaders.

The NITRD Program thus supports not only the vitality of the innovation ecosystem as a whole but the national NIT talent pool it nurtures. We are pleased that the PCAST, in its 2010 review of the Program, concluded that NITRD is widely and correctly viewed as "successful and valuable," and we are working, as noted throughout this testimony, to address PCAST recommendations for ways to improve our efforts.

I will now turn to the other questions the Subcommittee posed that I have not yet addressed.

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[11] See, for example, *Evolving the High Performance Computing and Communications Initiative to Support the Nation's Information Infrastructure*, the National Research Council, National Academy Press, Washington DC, 1995; and *Assessing the Impacts of Changes in the Information Technology R&D Ecosystem*, National Research Council, 2009.

NITRD Objectives and Critical R&D Issues

While maintaining their mission focus, the NITRD agencies make every effort through their NITRD Program activities to grapple with the most critical NIT R&D problems. Although the NITRD collaborative umbrella enables only coordination—not prioritization—of agencies' mission activities, each agency faces and responds to the challenge of pushing the cutting edge of technological change. To cite just a few areas, the NITRD agencies individually and together are investigating the implications of cloud computing for data-intensive science and high-end computation. Our agencies are also leading the government's major research effort to change the balance of power in cyberspace, so that legitimate uses are secure and malefactors can no longer attack at will. NITRD members are working on critical technical challenges at the upper limits of computing power and speed, such as energy conservation, nanoscale materials and techniques, and software architectures and applications for machines with hundreds of thousands of processors. The agencies are also pressing forward with improving software engineering for the long-lived, ultra-scale software-based systems that are the work horses providing many of the Nation's most vital capabilities across all sectors.

Amid the relentlessly accelerating rate of technological change of recent years, we in NITRD are also learning how to be more adept in adjusting our coordination emphases to be more responsive. The new ventures described above were created and became productive in record time for NITRD. Each of these is addressing significant national issues that require intellectual contributions from the NIT research community and advances in NIT R&D. The new SSGs and subgroups represent a different, more flexible model for NITRD collaboration—one in which collaborative groups are quickly formed to focus on emerging issues, do their work, and then may disband as their topical tasks conclude and new issues arise that need attention. NITRD's underlying PCAs will continue to exist, because they provide continuity in budget reporting over time. But shifting opportunities for short-term coordination activities are likely to be the new NITRD norm. These shifts align with the recommendations in the 2010 PCAST review of NITRD.

In my view, the value of the collaboration model in the NITRD Program, which involves both mission agencies focused on the "use value" of their missions and science agencies focused on "theory value," is illustrated by the political scientist Donald Stokes in his 1997 book *Pasteur's Quadrant*. Stokes defined a two-dimensional array of four types of R&D. His dimensions were "use value" and "theory value," and his point in making four quadrants was that high use value does not need to imply low theory value. And that high use-value science can generate high theory-value science, just as high theory-value science can generate high use-value science. Stokes pointed to the French scientist Louis Pasteur's groundbreaking work on causes and prevention of diseases as having high use value and high theory value (such research is said to lie in Pasteur's quadrant).

Stokes's concept usefully describes the essentially multidimensional nature of activities such as NIT research. That is, NIT R&D properly involves high use and high theory value. Computer science theory can arise from applied science, just as science research can arise from computer science research results; it is the constant interplay between the pure and the applied R&D sectors that generates many of the innovations that astonish us. We need pure research (such as computational complexity) and we need use-inspired research (such as arises when a mission agency seeks solutions to its science problems).

Research Opportunities and Academic and Industry Inputs

The research communities in academia and industry contribute to NITRD activities in a variety of forms. For example, in the past 12 months the NITRD agencies have finished their work on two major strategic plans—a five-year strategic plan for NITRD and a strategic plan for game-changing R&D to secure cyberspace. We are pleased that our cybersecurity R&D strategic plan, *Trustworthy Cyberspace: Strategic Plan for the Federal Cybersecurity Research and Development Program* will soon be released to the public and the NITRD plan is under review. Throughout both development activities, the NITRD agencies reached out extensively to engage the private sector in workshops, Requests for Input, wikis, and other forums.

One of the results in moving to include flexible, topic-focused coordination groups is that the NITRD Program can more conveniently draw upon academic and private-sector expertise across disciplines, sectors, and research and engineering domains in order to turn research results into practical applications.

A different form of outreach to the private sector takes place under NITRD member DOE/SC's Innovative and Novel Computational Impact on Theory and Experiment (INCITE) program. Since 2003, INCITE has promoted transformational advances in science and technology by competitively awarding large allocations of time on the agency's most powerful computing platforms ("leadership class" systems), as well as supporting resources and data storage, to industrial, federal, and academic researchers nationwide who lack access to such resources. For 2011, 57 INCITE awardees received a total of 1.7 billion processor hours. [12]

Importance of Federal NIT Investments

As discussed above, the history of NIT development has demonstrated the crucial role of federal investments. The results of these investments have spawned a myriad of technological innovations, novel products and communications capabilities, and an entirely new, multibillion-dollar economic sector in NIT that has been responsible for significant expansion in well-paying job opportunities. The multiplier effects of Federal NIT R&D—on both innovation and employment—are widely documented, perhaps most famously in the National Research Council's "tire tracks" graphic illustrating how the feedback loops mentioned above operate over time to move research discoveries into the marketplace. [13] There is little doubt that our country and the world are moving rapidly into an increasingly digital future. We in NITRD concur with PCAST that federal research leadership will continue to be an imperative if we are to sustain our preeminence in the networking and information technologies that we invented and developed.

Comments on H.R. 2020

The NITRD Program has benefited for 20 years from Congressional authorization and we look forward to this reauthorization. I believe that this draft legislation from the last Congress is well focused and will continue to aid our activities. Two small changes would, I believe, increase its value and focus.

- A. The draft legislation currently calls for a three-year cycle for updating the NITRD strategic plan and a two-year cycle for advisory committee review. I respectfully suggest that if both activities were put on a three-year cycle, there would be better linkage between them. The same might be true of a two-year cycle, but the 50% increase in reporting activity would not, in my opinion, be offset by gains in value to the program.
- B. A new section in the current draft legislation highlights cyber-physical systems and information management. As discussed above, we affirm the emphasis on cyber-physical systems. We respectfully suggest that, as also discussed above, "big data" is a better phrase than "information management" to characterize the advances required at this time.

These comments, I believe, are consistent with the findings of PCAST's 2010 review of NITRD.

Thank you very much for affording me the opportunity to provide testimony before the Subcommittee on Research and Science Education of the House Committee on Science, Space, and Technology. I will be happy to answer any questions you may have.

NITRD MEMBER AGENCIES

The following federal agencies, which conduct or support R&D in advanced networking and information technologies, report their IT research budgets in the NITRD crosscut and provide support for program coordination:

Department of Commerce (DOC)

- National Institute of Standards and Technology (NIST),
- National Oceanic and Atmospheric Administration (NOAA),
- Department of Defense (DoD),
- Defense Advanced Research Projects Agency (DARPA),
- National Security Agency (NSA),

[12] *http://www.doeleadershipcomputing.org/wp-content/uploads/2011/07/INCITE_IR_FINAL_7-19-11.pdf*

[13] In 2003, the National Research Council's Computer Science and Telecommunications Board (CSTB) updated the original 1995 tire tracks figure from the *Evolving the High Performance Computing and Communications* report in a new report, *Innovation in Information Technology* that summarized eight prior CSTB studies on the subject.

- Office of the Secretary of Defense (OSD) and Service Research Organizations:
- Air Force Research Laboratory (AFRL),
- Army Research Laboratory (ARL),
- Office of Naval Research (ONR).

Department of Energy (DOE)

- National Nuclear Security Administration (DOE/NNSA),
- Office of Science (DOE/SC).

Department of Homeland Security (DHS)

Department of Health and Human Services (HHS)

- Agency for Healthcare Research and Quality (AHRQ),
- National Institutes of Health (NIH),
- Office of the National Coordinator for Health Information Technology (ONC).

Environmental Protection Agency (EPA)

National Aeronautics and Space Administration (NASA)

National Archives and Records Administration (NARA)

NITRD PARTICIPATING AGENCIES

Representatives of the following agencies with mission interests involving networking and IT R&D and applications also participate in NITRD activities:

Department of Commerce (DOC)

- National Telecommunications and Information Administration (NTIA)

Department of Defense (DoD)

- Defense Information Systems Agency (DISA)

Department of Energy (DOE)

- Office of Electricity Delivery and Energy Reliability (DOE/OE)

Department of Health and Human Services (HHS)

- Food and Drug Administration (FDA)

Department of Interior

- U.S. Geological Survey (USGS)

Department of Justice (DOJ)

- Federal Bureau of Investigation (FBI)

Department of State (State)

Department of Transportation (DOT)

- Federal Aviation Administration (FAA)
- Federal Highway Administration (FHWA)

Department of the Treasury (Treasury)

- Department of Veterans Affairs

Director of National Intelligence (DNI)

- Intelligence Advanced Research Projects Agency (IARPA)

National Transportation Safety Board (NTSB)

Nuclear Regulatory Commission (NRC)

U.S. Department of Agriculture (USDA)

NITRD SSGs Participating Agencies

Cybersecurity

Department of Commerce (DOC)

- National Institute of Standards and Technology (NIST)

Department of Defense (DoD)

- National Security Agency (NSA)
- Office of the Secretary of Defense (OSD)

Department of Homeland Security (DHS)

Director of National Intelligence (DNI)

Executive Office of the President

- Office of Science and Technology Policy (OSTP)

National Science Foundation (NSF)

Big Data

Department of Commerce (DOC)

- National Institute of Standards and Technology (NIST)
- National Oceanic and Atmospheric Administration (NOAA)

Department of Defense (DoD)

- Defense Advanced Research Projects Agency (DARPA)
- National Security Agency (NSA)
- Office of the Secretary of Defense (OSD) and Service Research Organizations
- Air Force Research Laboratory (AFRL)
- Army Research Laboratory (ARL)
- Office of Naval Research (ONR)

Department of Energy (DOE)

Department of Health and Human Services (HHS)

- National Institutes of Health (NIH)

Director of National Intelligence (DNI)

Executive Office of the President

- Office of Science and Technology Policy (OSTP)

National Aeronautics and Space Administration (NASA)

National Science Foundation (NSF)

Health IT

Department of Commerce (DOC)

- National Institute of Standards and Technology (NIST)

Department of Defense (DoD)

- Telemedicine and Advanced Technology Research Center (TATRC)

Department of Health and Human Services (HHS)

- Agency for Healthcare Research and Quality (AHRQ)
- Assistant Secretary for Preparedness and Response (ASPR)
- Centers for Disease Control and Prevention (CDC)
- Food and Drug Administration (FDA)
- Indian Health Service (IHS)
- National Institutes of Health (NIH) Office of the National Coordinator for Health Information Technology (ONC)

Department of Veterans Affairs (VA)

National Science Foundation (NSF)

Executive Office of the President

- Office of Science and Technology Policy (OSTP)

Wireless Spectrum Technologies

Department of Commerce (DOC)

- National Institute of Standards and Technology (NIST)
- National Telecommunications and Information Administration (NTIA)

Department of Defense (DoD)

- Defense Advanced Research Projects Agency (DARPA)
- National Security Agency (NSA)
- Office of the Secretary of Defense (OSD) and Service Research Organizations
- Air Force Research Laboratory (AFRL)
- Army Research Laboratory (ARL)
- Office of Naval Research (ONR)

Department of Energy (DOE)

- Idaho National Laboratory (INL)
- Oak Ridge National Laboratory (ORNL)

Department of Homeland Security (DHS)

Department of Justice (DOJ)

Department of Transportation (DOT)

- Federal Aviation Administration (FAA)

Executive Office of the President

- National Economic Council (NEC)
- Office of Science and Technology Policy (OSTP)

Federal Communications Commission (FCC)

National Aeronautics and Space Administration (NASA)

National Science Foundation (NSF)

Chairman BROOKS. Thank you, Dr. Strawn.
We next recognize Dr. Lazowska for his five minutes.

STATEMENT OF DR. EDWARD LAZOWSKA, DIRECTOR, ESCIENCE INSTITUTE, BILL AND MELINDA GATES CHAIR

Dr. LAZOWSKA. Thank you, Chairman Brooks, Ranking Member Lipinski, the other Members of the Subcommittee for the opportunity to speak with you today. My name is Ed Lazowska. I am a long-time faculty member at the University of Washington. I recently co-chaired the working group of the President's Council of Advisors on Science and Technology, charged with reviewing the NITRD Program, but I am speaking today as an individual and endorsed by the Computing Research Association.

So I have 10 points that I would like to make in 30 seconds apiece, and here they are. First, information technology R&D is something that changes the world, and you see this in your own lives. You shop through Amazon, you get your movies from Netflix, you get books on your Kindle, you get the world of the Internet on your iPhone, you learn from Khan Academy, you have maps and directions and navigation and routing from Google and GPS, you have a Roomba robot vacuum cleaner, you have adaptive cruise control on your car. We all benefit from national security through information superiority. We all benefit. Your committee focuses on dramatic advances in science and engineering discovery that are enabled by information technology.

All of these are the results of IT R&D. I just spent the previous hour up the hall at a session called "Deconstructing the IPad," and it involved computer scientists, physicists, device engineers talking about the role of federal research and development in all of the technologies that underlie the IPad. Apple has done some amazing engineering to produce this miraculous device, but every piece of it, the GPS chip, the touch screen interface, the CPU, every aspect of that device can trace its roots to federally-funded research, and that is what your committee is focused on.

Second, information technology R&D drives our prosperity. It is not just the information technology industry. It is productivity gains in other sectors because of the use of IT. Economists agree that information technology has boosted U.S. productivity more than any other set of factors in the recent past.

Third, IT is the dominant factor in American science and technology employment. I hope we'll talk later about workforce issues, and offshoring is certainly a significant issue, but accounting for that, the Bureau of Labor Statistics projects that 60 percent of all new jobs in all fields of science and engineering in this decade will be for computing specialists. That's in this country. All right. So more than all the physical sciences, all of the life sciences, all of the social sciences, and all other fields of engineering combined. That's what they project for computer specialists in the next decade.

Fourth, federal support is a key part of this, and you heard from Dr. Strawn about this. You will hear more from others. Every major sector of the IT industry traces its roots to the federally-sponsored fundamental research program. It's the role of federally-sponsored research to take the long view. Industry R&D is the vast majority of it focused appropriately on the engineering of the next release for product.

Fifth, there's huge potential and huge need for further breakthroughs. I will defer talking about the specifics of that.

Sixth, many areas of IT R&D are crucial to national priorities and national competitiveness, and I am going to give you two local examples. Yesterday my young University of Washington colleague, Shwetak Patel, won a MacArthur genius award for work using machine learning to tell you exactly which devices in your home are consuming exactly how much electric power from a single device that you plug into a wall outlet anywhere in your house. Okay. It is just sort of miraculous in terms of incenting better use of energy, better energy efficiency.

A few years ago another young University of Washington colleague, Yoky Matsuoka, won a MacArthur genius award for work on prosthetics that couple directly to the nervous system. So this gives new hope to thousands of returning veterans who are impaired, disabled in various ways.

If you want breakthroughs in energy, in national security, in health care, in scientific discovery, in transportation, then you need breakthroughs in computer science. That's what powers those other examples. There is a set of federal agencies that understands this well, and there is a set that needs a better appreciation of it, and that is part of Dr. Strawn's job in the NCO—to bring those agencies together and cause them to pull together.

Seventh, the Nation is investing far less in IT R&D than is shown in the federal budget. Many agencies report the acquisition of computer technology to support research in other disciplines as part of their NITRD crosscut. This is a completely appropriate research expenditure, but it's not IT R&D, and we need to improve the reporting so that we know how much we are actually spending on this field.

Eighth, PCAST urged and I personally urge that the Federal Government needs a high-level, sustained expert strategic advisory committee for information technology R&D, something perhaps analogous to the former President's Information Technology Advisory Committee.

Ninth, computer science must be viewed as an essential component in STEM education. Every child and every adult needs fluency in computing and what we call computational thinking.

Finally, last, no other field comes close. Here is what PCAST said. "As a field of inquiry, Networking and Information Technology has a rich intellectual agenda, as rich of that as any other field. In addition, NIT is arguably unique among all fields of science and engineering in the breadth of its impact." That's why your work matters.

Thanks for the opportunity to share my view, and I, too, look forward to your questions.

[The prepared statement of Dr. Lazowska follows:]

PREPARED STATEMENT OF DR. EDWARD LAZOWSKA, DIRECTOR, ESCIENCE INSTITUTE, BILL AND MELINDA GATES CHAIR

Thank you, Chairman Brooks, Ranking Member Lipinski, and the other Members of the Subcommittee, for this opportunity to discuss the Federal Government's Networking and Information Technology Research and Development program. I am pleased to add my perspective on the Committee's questions, drawn from nearly 40 years in academia 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. However, I present this testimony as an informed individual and not as a representative of any particular organization, although my comments have the endorsement of the Computing Research Association.

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 today has been touched by IT, including commerce, education, employment, health care, energy, manufacturing, governance, national security, communications, the environment, entertainment, science and engineering. We have 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 productive and connected regardless of location, doctors empowered by virtual agents that can help navigate subtle drug interactions or diagnose with data rather than gut feelings, an emerging intelligent power grid working together with smart structures to more effciently utilize power resources, advanced robotics that will 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, movies and music and games that engage all our senses and take us to places no previous generation has ever seen, and a science and engineering enterprise primed with all the tools and data to enable discovery at a pace never before seen—all because of advances in computing systems, tools and services enabled by information technology 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 that all other sectors achieve from the application of IT. IT R&D creates new industries that create new jobs, and transforms existing industries in ways that increase their productivity and make them more competitive. In fact, it is this latter effect that has had the most profound impact on the economy and the Nation's competitiveness. Across every sector of the economy, businesses large and small have used IT systems, tools, and services to improve their productivity, boost their effciency, and increase their economic output to an unprecedented extent. Large companies like Walmart and United Parcel Service have used advanced IT tools to track and manage inventory on a minute-by-minute basis. Companies like Boeing and Procter & Gamble use high-performance computing in applications ranging from designing super-effcient airframes to modeling 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. And sites like Etsy and eBay allow individual artists or entrepreneurs to set up virtual storefronts and sell to the world. 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 IT-related systems, services, tools and methodologies have boosted U.S. labor productivity more than any other set of forces in recent decades.

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. Indeed, as the PCAST review of the NITRD program released last year noted, *"All indicators—all historical data, and all projections—argue that [Networking 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."* [1] Bureau of Labor Statistics projections indicate that more than 60% of all new jobs in all fields of science and engineering in the current decade will be for computer specialists. Increasing the number of graduates in IT fields at all levels should be a national priority; the NITRD program should 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 itself is the product of a vibrant research ecosystem—an ecosystem comprised of university research in academic departments, industrial research facilities, 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. [2]

The federal role in this system is largely limited to investments in long-term, early stage scientific research, typically at U.S. universities. This research often occurs many years,or even decades, before a product is developed for the marketplace.

The great majority of industry-based research and development is of a fundamentally different character than university-based research. Industry-based research and development is, by necessity, much shorter term than the early-stage research performed in universities. It tends to be focused on product and process development, areas which will have more immediate impact on business profitability. Industry generally avoids long-term research because it entails risk in several unappealing ways. First, it is hard to predict the outcome of fundamental research. The value of the research may surface in unanticipated areas. Second, fundamental research, because it is published openly, provides broad value to all players in the marketplace. It is difficult for any one company to "protect" the fundamental knowledge gleaned from long-term research and capitalize on it without everyone in the marketplace having a chance to incorporate the new knowledge into their thinking. Those companies that do make significant fundamental research investments tend to be the largest companies in the sector. Their dominant position in the market increases the likelihood that they benefit from any market-wide improvement in technology basic research might bring. For example, IBM and Microsoft are among the companies that invest the largest proportion of their R&D expenditures on research looking out more than one product cycle, but at Microsoft, as reported by PCAST, it is estimated that this still constitutes less than 5% of total R&D. At most other companies, it is far less. University research does not supplant industry research, or vice versa.

An example might be instructive here. Apple's IPad is a seemingly miraculous little machine. Available for about $500, 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 then 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 as recently as 1994, 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, 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. Without exception, however, all these technologies have their roots in early-stage scientific research, and all bear the stamp of federal government 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 in-

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[1] *Designing a Digital Future: Federally Funded Research and Development in Networking and Information Technology*. Report to the President and Congress, President's Council of Advisors on Science and Technology, December 2010.

[2] *Information Technology Research: Investing in Our Future*. Report to the President, President's Information Technology Advisory Committee, February 1999.

tuitive 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 spent over two years adapting it for the first iPhone.

A similar case can be made for the processor—the brain of the device—which has its 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 far cry 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, on Reduced Instruction Set Computing (RISC) and Microprocessor without Interlocked Pipeline Stages (MIPS) technologies, as well as Very-Large-Scale Integration (the process of creating integrated circuits by combining thousands of transistors into a single chip)—technology that 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, accelerating the pace of innovation—and work at universities in particular helped generate the people and ideas that fueled industry's advancements.

It is possible to draw similar timelines 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 maybe 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. And it shows that federal support for early stage research is truly an investment—an investment that has a history of demonstrating extraordinary payoff in the explosion of new technologies that have touched nearly every aspect of our lives, and in economic terms—in the creation of new industries and literally millions of new jobs.

There Is Tremendous Potential—and Tremendous Need—for Further Breakthroughs

The history of innovation in computing is impressive, but the future opportunities are even more compelling. Research in the future of networking, revolutionizing transportation, personalizing education, powering the smart grid, empowering the developing world, improving health care, enabling advanced manufacturing and driving advances in all fields of science and engineering are all compelling challenges well suited to advancements in IT. Indeed, without continued progress in computing research, our ability to address key national and global priorities in energy and transportation, education and life-long learning, health care, and national and homeland security will be seriously constrained.

Many Areas of IT R&D Are Crucial to National Priorities and National Competitiveness

In its 2010 report *Designing a Digital Future*, PCAST identified three areas of research that the Council felt were *"particularly timely and important."* I support the Council's recommendations. They called for:

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

In addition, the Council identified a broader set of research frontiers of the field that require increased focus from NITRD agencies, including:

- A broad multi-agency research program on the fundamentals of privacy protection and protected disclosure of confidential data.
- A collaborative research program that augments the study of individual human-computer interaction with a comprehensive investigation to understand and ad-

vance human-machine and social collaboration and problem-solving in a networked, on-line environment.

- Fundamental research in data collection, storage, management, and automated large-scale analysis based on modeling and machine learning.
- Research in advanced domain-specific sensors, integration of NIT into physical systems, and innovative robotics in order to enhance NIT-enabled interaction with the physical world.

It is critical to recognize that many areas of IT are now equal in importance to high performance computing (HPC) as measures of our nation's competitiveness. Twenty years ago, at the time of passage of the High Performance Computing and Communications Act of 1991 (which established the modern NITRD program), it was appropriate that much of the focus of the federal effort in computing was on the importance of HPC to scientific discovery and national security. Today, 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 (e.g., robotics); large-scale data capture, management and analysis (critical, today, to scientific discovery and national security); systems that protect personal privacy and sensitive confidential information; scalable systems and networking; software creation and evolution; and critical infrastructure protection (e.g., the financial system, the power grid, the air traffic control network). World leadership in all of these areas is crucial to our nation's security and prosperity.

The Nation Is Investing Far Less on IT R&D than Is Shown in the Federal Budget

One of the difficulties of assessing the adequacy of the federal investment in various areas of IT R&D is the ambiguity of the data about IT R&D investments reported by the various agencies participating in NITRD. PCAST found that much of what gets reported by NITRD agencies represents spending on IT that supports research in other fields—such as computing clusters for scientists in other fields—and not spending on researchin information technology. In some cases, the discrepancy in reporting leads to a dramatic over-reporting of IT R&D investments by the agencies: at one major NITRD agency, PCAST estimated that *only between 2 percent and 11 percent of reported NITRD expenditures truly represented investments in IT R&D.* I share PCAST's concern that *"by leading policymakers to believe that we are spending much more on such activities than is actually the case, this discrepancy contributes to a substantial, systematic underinvestment in an area that is critical to our national and economic security."*

The Federal Government Needs High-Level, Sustained, Expert Strategic Advice on ITR&D

Another key recommendation contained in the PCAST report with which I 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. I was pleased to see recognition of this in H.R. 2020, and I feel it is imperative that the recommendation of the PCAST report be implemented.

Computer Science Must Be Viewed as 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 a large number 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 like ACM's Education Policy Committee have expended great 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.

In Some Areas, H.R. 2020 Did Not Go Far Enough

As co-Chair of the Computing Research Association's Government Affairs Committee back in 2009, I joined in endorsing the passage of H.R. 2020, the *Networking and Information Technology Research and Development Act of 2009*. I believe the Act would make the NITRD program stronger by enacting several of the recommendations of PCAST. In particular, I was pleased that the NITRD Act included a requirement that the NITRD program undergo periodic review and assessment of the program contents and funding, as well as develop and periodically update a strategic plan—both necessary in helping ensure the significant federal investment in IT R&D is used as effectively as possible. This review and assessment is best done by an independent standing advisory committee composed of experts from academia, industry and government. As noted earlier, the creation of such a committee is essential.

I do not believe the Act went far enough in addressing the nation's IT workforce and education needs. As CRA noted in a joint letter with the Association for Computing Machinery and the National Center for Women and Information Technology back in March 2009, we felt it is critical that federal efforts to educate young people in computer science improve, and that investments recognize that all racial, gender and socioeconomic groups are crucial to the continued health of and future innovations in the computing field. The three organizations made four specific recommendations for the bill, which I support:

- Promote computing education, particularly at the K–12 level, and increased exposure to computing education and research opportunities for women and minorities as core elements of the NITRD programs;
- Require the NITRD program to address education and diversity programs in its strategic planning and road-mapping process;
- Expand efforts at NSF to focus on computer science education, particularly at the K–12 level through broadening the Math Science Partnership program; and
- Enlist the Department of Education and its resources and reach in addressing computer science education issues.

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.

Chairman BROOKS. Thank you, Dr. Lazowska.

Our next witness is Dr. Sproull.

STATEMENT OF DR. ROBERT SPROULL, DIRECTOR OF ORACLE LABS

Dr. SPROULL. Good afternoon. I am Robert Sproull, recently retired as Director of Oracle Labs. I want to thank Chairman Brooks and Ranking Member Lipinski and Members of the Subcommittee for an opportunity to appear before you today to offer an industrial perspective. While I do not represent any specific company, most of my career has been doing research or managing research with industrial labs; Xerox Palo Alto Research Center, Sun Microsystems Labs, and most recently Oracle. But I have also been a university researcher on federally-funded projects, an advisor to high-tech venture capital investors, and a researcher in a federal laboratory.

My main point is that industrial research and innovation alone will not sustain the extraordinary advances of the IT economy that the two preceding witnesses have described. This growth and advance over the last 50 years have depended on high-risk, high-reward, long-term research, mostly performed in academia and funded by the U.S. Government. Industry works closely with academic research so as to harness their findings and expertise as essential ingredients in its offerings.

The NIT economy is a complex ecosystem in which government, industry, and academia interact closely. Industry excels at developing and producing complex products, incremental innovations, compelling product designs such as the IPad, and global markets. Academia excels at high-risk research on fundamental problems with uncertain economic payoffs, and venture capital funding propels to market product-ready technologies that might be ignored or even fought by large companies. The biggest payoffs emerge from interactions among all of these groups.

The ecosystem has produced extraordinary results. Its complex behavior is sketched in the tire tracks diagram that Dr. Strawn referred to, and I will present it to you for your enjoyment. This is a slide that explains how to interpret it. Time will go from left to right. This is the portable communication technology characterized by cell phones. University research activity is depicted with a red horizontal line. Industrial research activity is shown with blue lines, and notice interactions between them. You will see even more interactions in a moment, depicted by the black arrows. And emerging products are depicted with dashed black lines, and when product streams reach a billion dollars, they are shown by solid green lines.

So there are 19 sectors of the IT economy. This was published in the diagram that was produced in 2003. Each of these sectors yields revenues of over a billion dollars each. We have a new update underway to illustrate even more recent successes such as Internet search and others in social networking.

Please note that the path to a billion dollar business is not a simple progression from fundamental research to applied research to development to delivery. Nor does a single idea or breakthrough suffice to build an industry. Rather, dramatically new capabilities build on an accumulation of many varied research and innovation results. It may take 15 years or more to develop the technologies and markets of a billion dollar business.

The ecosystem depends on research, especially long-term fundamental research. This research is high risk and unpredictable. It is impossible to predict the degree of impact of a research result or how it ultimately may be used in products. The long diagonal lines in the diagram show only some of the cases where work in one area became essential in another area.

Government-funded long-term fundamental research has played an essential role in each of the trajectories depicted in this diagram. For example, ARPA in the '60s recognized that information technology could address many defense problems and undertook programs of long-term research to improve its effectiveness, and they are responsible for many, especially on the left-hand side, of the early technologies.

Today, solutions to many more problems facing the government will depend critically on NITRD techniques. National priorities in energy, transportation, health, and cybersecurity all depend on NIT and will benefit from long-term research. These priorities will also require short and medium-term investments, as well as a great deal of routine IT, but we must not let these components undercut long-term investments. As ARPA and other agencies have shown, it's the long-term research that leads to extraordinary advances.

As recommended in the PCAST report, the NITRD Program should be expanded as necessary to match the broadening scope of NITRD investments made by the Federal Government. Although the program was started to coordinate high-performance computing investments, the newer priorities dramatically increase the scope of federal NRD, NITRD investments and coordination requirements.

I have been extremely fortunate to have been part of the research community of the NITRD ecosystem. It's been exciting and rewarding, and it remains so. The fact that we have come so far does not reduce the challenge or potential impact of research problems we face today.

Thank you.

[The prepared statement of Dr. Sproull follows:]

PREPARED STATEMENT OF DR. ROBERT SPROULL, DIRECTOR OF ORACLE LABS

Thank you, Chairman Brooks, Ranking Member Lipinski, and the other Members of the Subcommittee for this opportunity to discuss the Federal Government's Networking and Information Technology Research and Development program. I am pleased to offer my perspective on your questions based on more than 40 years of experience doing or managing computing research in academia and industry and also advising high-technology venture capital investors. Among other roles, I currently serve as the Chair of the National Research Council's Computer Science and Telecommunication Board (CSTB), and recently retired from Oracle as the Director of Oracle Labs. This is an applied research laboratory first started by Sun Microsystems in 1990 and retained by Oracle when they acquired Sun in 2010. I present today's testimony as an informed individual and not as a representative of any particular organization.

Introduction

Extraordinary economic and societal benefits have exploded from the U.S. NITRD ecosystem, which is a complex interplay of government, academia, and industry that dates back more than 40 years. Some of the technologies themselves have improved extraordinarily, such as the price/performance of microprocessors; equally, new markets have grown explosively as networking infrastructure and low-cost electronics have enabled innovative products and businesses. I will describe below some of the aspects of this ecosystem, especially the importance of fundamental research and the interplay of government, academic, and industrial roles.

I wish to stress at the outset, however, that this ecosystem would not have been born, nor would it be successful today, without a vigorous, thoughtful strategy of federal investment in fundamental research in NIT. Especially important in the early days were programs of long-term research sponsored by NSF and ARPA. An important milestone was the High Performance Computing Act of 1991, which recognized the importance of high-performance computing to federal missions, especially those of Defense and Energy. But as IT technology itself became more pervasive in the U.S., signaled most vividly by the blossoming of the World Wide Web in 1993, a wide class of NIT technologies became critical to short- and long-term requirements of many more federal agencies. The Act and its research coordination role were appropriately extended to address the expanded set of challenges. This extension in scope must continue: today, NIT's role in national security, national competitiveness, and national priorities is far broader than high-performance computing alone.

NITRD Goals

The nation has identified advances in energy, transportation, health, and cybersecurity as important national priorities. I concur with the PCAST NITRD Working Group, on which I served, that these are important drivers where NIT research and innovation can make enormous contributions, and with the PCAST report recommendation to expand NITRD's purview as necessary to address these areas. H.R. 2020 is an excellent first step, identifying cyberphysical systems in particular for more attention. The recently announced National Robotics Initiative is a concrete example of investing in cyberphysical systems research. But there is an even wider need for cyberphysical systems in achieving national priorities, for example as part of controllers and systems that achieve efficiencies in energy and transportation, and for monitoring patient health. Indeed, the national priorities show a broad panorama of areas, including high-performance computing, in which NITRD investments will be essential.

Sun Microsystems' Research Lab, an Industrial Contributor to the NITRD Ecosystem

Sun Microsystems was founded in 1982 to build advanced computer workstations, based on results of research conducted primarily at Stanford, Berkeley, and Bell Laboratories. In 1990, Sun created a research laboratory. I was a founding member and eventually became its director. When Oracle acquired Sun in 2010, they retained the lab as a way to start Oracle Labs. I retired from Oracle earlier this year.

I characterize the lab as an "applied research lab," in that most of its research projects, though risky, have medium-term objectives (e.g., less than three years) that, if successful, would have a significant impact on a Sun product or product line. Our job is to selectively explore risky ideas and reduce their risk to a level that would be acceptable to an engineering team. Ideally, our research team would then transfer to the engineering organization, carrying its ideas and insights into a larger engineering team. We like to say that "technology transfer is a contact sport," meaning that the most effective transfers from research to engineering are those that transfer people.

The lab was deliberately kept small, with a budget of about 2% of Sun's total R&D budget. SunLabs hires mostly Ph.D.s in computer science and engineering fields, but also high caliber college graduates in those fields. When the lab started, our CEO, ScottMcNealy, explicitly asked us to be "eyes and ears" for Sun, to participate in the global IT research community, to learn from it, and to contribute to it. Our researchers are nationally and internationally known, attending and presenting papers at international conferences.

SunLabs does very little fundamental or long-term research. An applied research project might develop broadly applicable results, but that is not its principal objective. In order to import a broad range of fundamental new ideas, we pay careful attention to academic researchers and their results, as McNealy requested.

Sun evolved a system of "collaborative research" with academic partners. We would contribute money or equipment to an established university research project that we judged might be able to contribute to Sun's technologies. Then our researchers would interact closely with those in the university. We encouraged academic researchers and graduate students to work with us at Sun, as consultants or student interns, to learn from their ideas—again through people. For example, Sun's embracing of Reduced Instruction Set (RISC) processor technology—a technology behind most computer processors in use today—was accelerated by collaborating with the RISC research group at U.C. Berkeley and by consulting help from its principal investigator, Prof. David Patterson. This model served Sun well, and helped us sustain innovation at a time of rapid technological change. These collaborative interactions with academia also allowed us to present challenging Sun problems to academics and thus influence academic research agendas.

Though Sun Labs managed almost all the *research* projects at Sun, it was responsible for only a fraction of Sun's *innovations*. The product engineering organizations, developing both hardware and software, routinely innovate. For example, Sun is famous for introducing in 1984 the "network file system" (NFS), which allowed computers to share files over a computer network. Though innovative, its development was not the direct result of research.

Incidentally, I dislike the word "breakthrough," because it is too often assumed that breakthroughs are the only objective of research and stem only from research, especially fundamental research. To the contrary, high-impact innovations can emerge in many ways, and sometimes the principal reason for the high impact—and thus perhaps the perception of a "breakthrough"—may simply be a sharply lower price or rapid market penetration. But these dramatic advances usually depend on much varied research, much incremental, perhaps some revolutionary, and often far earlier than the apparent "breakthrough."

The NITRD Ecosystem—The Big Picture

As part of an early assessment of the High-Performance Computing Act of 1991, a study by the National Research Council developed a graphic presentation known as "the tiretracks diagram" to illustrate some of the features of the complex interactions among government, academic, and industrial players that lead from early research to several billion-dollar subsectors of the IT economy. The graphic is attached below.

The graphic charts the development of technologies from their origins in industrial and federally-supported university R&D, to the introduction of the first commercial products, through to the creation of billion-dollar industries and markets. The principal features of the NITRD ecosystem that this diagram illustrates are:

- Contributions are made by universities (usually federally funded) and industry, in varied orders and magnitudes. Ideas and people often contribute to different paths; there are frequent flows from academia to industry and vice versa. There is no direct path from research to impact.
- Initial research often takes a long time to pay off; 15 years is typical.
- Research often pays off in unanticipated ways: developments in one sector often enable advances in another, often serendipitously.
- Innovations occur at all points along technology trajectories, not only in research settings.
- University and industry research are different: university research favors long-term fundamental problems, while industry generally focuses on the next product cycle or two (at most a few years). Results of university research are public and available to all, creating a challenge for industry uptake.

The original diagram produced by the NRC in 1995 identifies nine billion-dollar sectors. The updated diagram produced in 2005 shows 19 billion-dollar subsectors of the IT economy, each of which bears the clear stamp of federal investment, usually in high-risk research with uncertain commercial application or payoff. The Council is at work now producing the next version of the chart, and they are likely to identify several new billion-dollar subsectors—search and social networking, for example—that have emerged just since 2003.

The NITRD Ecosystem—a Java Example

In the late 1990s, Sun Microsystems introduced the new Java programming language. Although new programming languages are rarely adopted widely, Java became popular because of its ability to run robustly on many different computer types and because of its modern design, especially features that reduced some of the tedious chores of programming; that is, it increased programmer productivity. Many IT staffs and product developers embraced Java to program their products and services. Today, Java is often taught to high school students as their first programming language. One of the reasons Oracle acquired Sun is that much of Oracle's product suite had come to depend on Java.

Java was designed by James Gosling in 1991 as part of a research project exploring ways to use graphical point-and-click user interfaces to control televisions, set-top boxes, kitchen appliances, and other consumer gear. This product objective did not succeed, but Java found a foothold in the mid '90s as a way to program Web browsers to create animated and interactive experiences. Early releases for this purpose reached a large number of programmers, the language became quite popular, and Sun went on to develop versions for conventional computer systems (as opposed to browsers).

Java's design and implementations draw heavily on preceding research in many areas. Object-oriented programming languages had long been studied by industry and academia. Especially important was the SmallTalk language, developed by Xerox researchers in the 1970s, inspired by a language named Simula, developed by Norwegian researchers in the 1960s. Research to speed up execution of SmallTalk programs became a popular focus of university research on a wide range of fundamental language implementation problems. For example, a graduate student at Stanford, Urs Holzle, developed a revolutionary way to generate fast code for the

Self language, a close kin of SmallTalk. He and others founded a startup, Animorphic, to exploit this technology in a commercial SmallTalk system to compete with other SmallTalk offerings from a small group of startups (none of which survive today).

When Java became popular, the Animorphic team quickly retargeted their work to a Java implementation, judging that it would have greater commercial value than SmallTalk. Sun, looking for ways to speed up its own Java implementations, bought Animorphic, and the team incorporated their technology into Sun offerings, where it became known as "HotSpot technology."

This is but one of many threads from research to product that contributed essential components to Java technology.

This detailed glimpse of one of Java's technology paths shows the NITRD ecosystem at work. The players are global; there are complex interactions among industry andacademic researchers; people and ideas flow rapidly; startups play an important role whether or not they ultimately succeed as standalone businesses; fundamental innovations may take a long time to reach mainstream products; a commercial success will track back to countless research projects and results, many of them funded by the Federal Government. The ecosystem collapses without federal support of fundamental research.

Characteristics of the Ecosystem

Using the term "ecosystem" to describe the complex interactions among participants in NITRD activities may seem a stretch, but the term is apt. There are many distinct players, with varied but blurry roles, and complex dependencies. As we've seen, an IT product depends on other NITRD activities in complex ways akin to the dependencies in a biological system. Different players perform complementary roles. Long-term academic research provides new results whose impact cannot be predicted at the time. Industry amplifies these results through its own applied research and product development processes. The overall health of the system depends both on funding from government and from revenues received for products and services offered by healthy IT businesses.

Like a biological ecosystem, the NITRD ecosystem could be disrupted or damaged inadvertently. The NRC report *Assessing the Impacts of Changes in the Information Technology R&D Ecosystem* addressed exactly this concern in 2009. It concludes that federal investment in research is essential and dangerously thin. It points to the importance of venture funding. It also points out that the ecosystem includes customers: "The most dynamic IT sector is likely to be in the country with the most demanding IT customers and consumers." Thus, for example, improving U.S. broadband networking is essential to creating the demand to develop world-class innovative services.

The most dangerous and least visible threat to the ecosystem is that we all focus on short-term research and payoffs, thus underinvesting in the long-term research that may lead to extraordinary technical advances and returns.

Investing in fundamental research is risky, and the amount and character of payoff cannot be predicted. But federal sponsors have an excellent record of directing fundamental research, in concert with the research community itself. DARPA, for example, pursues military needs, and its long-term vision and investments have resulted in fundamental and high-payoff results, such as interactive computing, networking, and RISC microprocessors. NSF's recognition that digital libraries would become important led to high payoff in search engines, which can be seen in today's search offerings from Google, Yahoo, and Microsoft. The wisdom of long-term federal research investments is evident in the productive ecosystem they have spawned.

As I remarked in my introduction, the national goals in energy, transportation, health, and cybersecurity are excellent guides for today's NITRD research investments. Who knows what billion-dollar NIT industries may emerge from research toward these goals?

The Research Workforce

I want to offer a few comments on the workforce available to industrial research groups. Note that this is a small subset of the overall IT workforce. I offer these comments to emphasize the varied nature of skills and training in the workforce.

At SunLabs, we hired mostly Ph.D.s, many fresh out of graduate school. Candidates come from all over the world. In most cases we know of students finishing their degrees because we have ongoing collaborations with their professors or the students themselves. In all cases, we seek candidates who have demonstrated research skills in areas aligned with the research project we are staffing. For example, a project to explore new ideas in building Java "virtual machines" seeks candidates who have built virtual machines, garbage collectors, or other programming-language artifacts as part of their academic research. Consistent with our objective of transferring technology by transferring people, we seek researchers adept at building systems and willing to join engineering teams.

Although we expect staff to work from one of our two lab locations in the U.S., this is not always possible. Some candidates have family constraints that prevent a move. Some foreign nationals cannot obtain visas, or must work from abroad until a visa can be obtained. The international Internet makes remote work ("dispersed R&D") possible, but not preferable. Location still matters, but as networking improves, it matters less.

Understanding Federal Research Investments

The PCAST Working Group that examined the NITRD program had trouble determining the levels of research investment in different areas because of difficulties in labeling and measuring expenditures. In industry, we make clear distinctions between different kinds of investment in IT, in part so that the investments can be balanced appropriately.

First, support of fundamental and applied *research*. The goals of this work are too risky to depend on results to meet customer or market needs.

Second, investments to develop new IT products and services, some for sale and some for internal use. These developments may be routine or highly innovative, but the development itself is not very risky: schedules, milestones, tests, and periodic releases characterize the work.

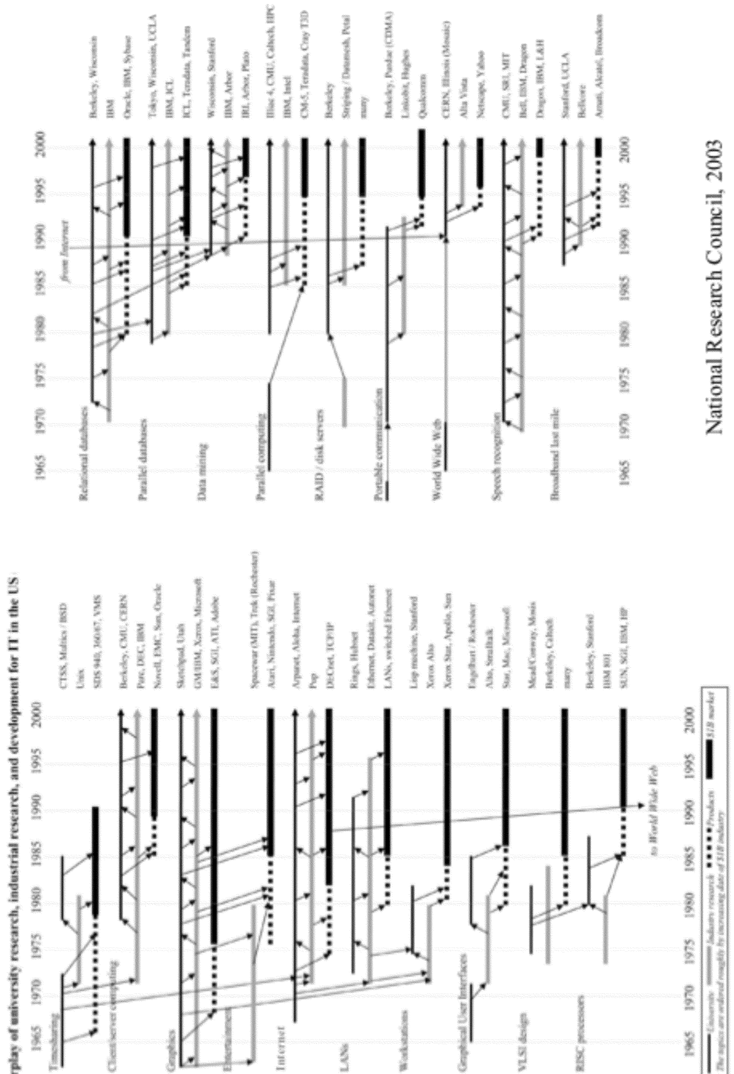
Finally, investments in NIT infrastructure that support all parts of the business, including the two items mentioned above, NIT research and NIT development. These investments are usually the least risky and innovative of all, and are usually driven by estimates of computing and networking capacity needed. As NIT infrastructure becomes necessary to support almost all business activities, these expenses are similar to those for space and utilities, and are accounted as an overhead for the activities they support.

Federal budget reporting makes it difficult to distinguish these three classes of investment. Infrastructure, in particular, should not be characterized as an NIT R&D investment unless it supports NIT R&D itself. For example, a Web server that provides citizen access to an agency's database is not an NITRD investment, though it is a use of NIT. While distinctions between research and development (the first two categories) are sometimes blurry, the appropriate measure is one of risk and reward. It is the risky but potentially broadly valuable investments that should be classified as research.

NITRD program coordination would be improved if the participating NITRD agencies were required to report their R&D expenditures more clearly. To coordinate research activities, actual research investments must be reported. Either better categories such as the ones I've outlined or more thorough line-item reporting would help. This is an area where a bill such as H.R. 2020 could contribute.

Conclusion

The NITRD program has demonstrated an ability to coordinate federal investments in essential research, starting with high-performance computing and now extending to a broader set of national goals. The challenge now, for sponsors and researchers alike, is to make the case to an increasingly broad set of NITRD mission agencies that long-term investments in fundamental NITRD research lead to large rewards for their missions and for the nation.



Interplay of university research, industrial research, and development for IT in the US

National Research Council, 2003

Chairman BROOKS. Thank you, Dr. Sproull.

Next our final witness is Dr. Robert Schnabel.

STATEMENT OF DR. ROBERT SCHNABEL, DEAN, SCHOOL OF INFORMATICS, INDIANA UNIVERSITY, SCHOOL OF INFORMATICS

Dr. SCHNABEL. Chairman Brooks, Ranking Member Lipinski, and distinguished Members of the Subcommittee, thank you so much for the opportunity to speak with you today. I'm Bobby Schnabel. I'm Dean of the School of the Informatics at Indiana University. In this testimony I'll represent both my university role and also my national roles in computing education with ACM and with the industry non-profit coalition Computing in the Core.

I will speak primarily to the education and workforce issues that have been mentioned and which are essential to keeping our Nation's innovation and economy strong.

My fundamental points are these. The workforce demand in computing and IT is high, it is growing, and it greatly exceeds our current and projected capacity. To meet that demand we will need to educate both a greater number and a greater—more diverse set of people in computer science and IT disciplines. And to reach the required enrollments at the university levels we really need to bolster computer science education at the K–12 level, where, unfortunately, the current delivery of computer science education is meager and actually diminishing.

I strongly support the inclusion that you have made of workforce education and diversity issues in the NITRD legislation and urge you to assure that NITRD agencies are accountable to report back what they are doing to improve K–12 education and diversity.

And finally, I strongly encourage you bringing the Department of Education back into the NITRD Program.

Now, I could stop there and possibly set the record for brevity, but I will elaborate a little bit. First, I want to express my sincere appreciation for your work on the NITRD legislation overall. NITRD is at the core of what we do in computing research at U.S. universities and has been spoken by many here, the research advances under the NITRD Programs have been the lifeblood that have fueled much of our Nation's economic growth.

As the scope of computing continues its marvelous expansion, it's crucial that the scope of the NITRD Programs expand as well. A particularly important area in my estimation is health IT.

Now, returning to workforce, as the SRI study that has been alluded to validated, the demand for IT professionals is much greater than the supply, both in total and in almost all of the subcategories of IT. Universities have actually done a very good job of evolving with the times in turning out graduates that industry really values. They are simply not turning out nearly enough of them, and when you look at the reason for that, a good part of the problem is the lack of rigorous computer science at the K–12 level.

A recent report called, "Running on Empty," that was issued by the ACM and the Computer Science Teachers' Association showed that computer science at K–12 really faces a triple whammy. It is the lack of computer science standards that have been implemented by the states, the lack of rigorous computer science courses that count as core graduation requirements, and the lack of computer science teachers. An explanation I sometimes get for that is rather simple. Computer science wasn't around 50 years ago when much of this curriculum got solidified, and since then there has simply been no room at the end.

So for states to strengthen computer science K–12 education, I believe that the encouragement and support at the federal level is essential, and NITRD can help significantly with this. In my written testimony I discuss a number of helpful steps.

One important example of that is support for the very exciting new computer science advanced placement course that is being developed and the accompanying CS 10K Project, which is attempting to train 10,000 new teachers to be able to deliver that course.

Another simple but really key component is just assuring, as has been said, that all federal STEM legislation clearly and explicitly state that computer science is part of the scope of that legislation.

So to conclude and to come back to the comments about workforce, if this hearing had been held yesterday, it would have been difficult for me to attend. Our School of Informatics was holding its annual career fair where we had 80 companies in the largest space that our campus can accommodate, interviewing our students. The message that we got from those companies is the same one that I hear every year, and that is that the three to four hundred students who will graduate this year is a fraction of what they would like to hire from us.

As I look to my colleagues and they are nodding, that message could be repeated at virtually every university in this country. I really appreciate your dedication to helping our Nation solve that problem and will look forward to responding to your questions.

Thank you.

[The prepared statement of Dr. Schnabel follows:]

PREPARED STATEMENT OF DR. ROBERT SCHNABEL,
DEAN, SCHOOL OF INFORMATICS,
INDIANA UNIVERSITY, SCHOOL OF INFORMATICS

On behalf of Indiana University, its School of Informatics, the Association for Computing Machinery, its Education Policy Committee, the members of the Computing in the Core Coalition and myself, thank you, Chairman Brooks, Ranking Member Lipinski, and Members of the Subcommittee, for the opportunity to share comments on the Networking and Information Technology Research and Development (NITRD) program with you.

I have been involved in computing and the computing community for nearly 40 years. Prior to assuming my current dean position in 2007, this includes 30 years at the University of Colorado at Boulder as a professor of computer science, and service as chair of Computer Science, associate dean for academic affairs in the College of Engineering and Applied Science, Vice Provost for Academic and Campus Technology and CIO, and founding director of the Alliance for Technology, Learning and Society (ATLAS) Institute. I also am a co-founder and executive team member of the National Center for Women & Information Technology.

Computing is transforming our world—driving innovation in numerous fields, leading to entirely new multi-billion dollar industries creating thousands of new jobs, and transforming how we live, work, and socialize. Fueling this engine of innovation are the investments that various agencies have made in the computing research enterprise and the workforce that supports it. The Networking and Information Technology Research and Development program (NITRD) plays a key role in coordinating and focusing these federal programs.

Summary of Recommendations Concerning Education and Workforce

H.R. 2020, as passed the House in the 111th Congress, proposes enactment of the President's Council of Advisors for Science and Technology (PCAST) recommendations for assessment and strategic planning by the NITRD program. These elements will strengthen the overall NITRD program. We particularly appreciate and strongly support the committee's inclusion in H.R. 2020 that NITRD address both education and workforce issues, including the diversity of the IT student and workforce population, as part of its strategic planning process.

If we are to continue to discover and develop the innovations that have created new industries and transformed others, we need to ensure a healthy IT workforce that is skilled and large enough to meet the nation's growing IT needs, and reflects the gender and racial diversity of our nation. While university computing and IT education and research programs have done a good job of changing with the times to meet current needs, the education pipeline feeding our workforce is not producing enough graduates in IT fields to meet the growing needs of the computing industry, let alone the other industries that rely on computing and the public agencies that need computing professionals. In addition, women and many minority groups are greatly underrepresented among computing and IT students and in the IT workforce, depriving the nation both of potential skilled workers and of the innovation that results from diverse teams.

A key element of this pipeline is in crisis and is directly related to the insufficient number of students in university computing and IT programs: K–12 computer science education. If we do not address the issues in K–12 computer science education, students will have few opportunities to experience this critical discipline or its concepts before higher education and our computing pipeline will continue to suffer. NITRD and the National Coordinating Office (NCO) can play a key role in addressing obstacles standing in the way of strengthening K–12 computer science education. As the committee works toward considering a new NITRD reauthorization, we recommend Congress add additional provisions for NITRD programs to specifically address the systemic issues facing K–12 computer science education, namely:

- NITRD programs should report to NCO what steps they are taking to address K–12 computer science education reform.
- Include the Department of Education in the NITRD program.
- Include and clearly define computer science in federal education programs.
- Create state planning and implementation grants for computer science K–12 curriculum and build national networks of support for K–12 computer science education.
- Create pre-service and professional development opportunities for K–12 computer science teachers.

The remainder of this testimony expands upon the preceding points.

NITRD's Important Role in Sustaining Innovation

Information technology, driven by public and private research funding, has transformed our society and our economy. As amazing as the progress of the last 20 years is in this regard, the future can be even more amazing, if public and private players sustain our IT research ecosystem. Historically, the diversity of our NITRD agencies has been a major strength, fostering multiple approaches to complex problems. The Internet began as a Defense Advanced Research Projects Agency (DARPA) project, grew with National Science Foundation (NSF) support and blossomed with commercial funding. The Human Genome Project was a triumph of biomedicine and IT, building on National Institutes of Health, DARPA, NSF and Department of Energy research and birthing personalized medicine.

A key element of the NITRD program involves fostering communication and coordination across 13 federal agencies where IT is relevant. This creates a rich ecosystem for information technology research and development, spanning many programs. The legislation proposed in the 111th Congress strengthens the program by addressing several key recommendations forwarded in 2007 by the President's Council of Advisors on Science and Technology.

As the National Coordinating Office (NCO) begins to develop strategic plans for computing research, it also should consider how agencies are meeting the ongoing challenge of supporting the continual broadening of the field of computing and information technology. I am closely acquainted with this broadening as the Dean of the School of Informatics at Indiana University, which offers a variety of undergraduate and graduate degrees in both computer science and informatics to meet the growing needs of the NIT workforce. These programs include research ranging from the foundational aspects of computer science to a wide range of applications and human and societal implications of computing and IT. It is important that NITRD programs embrace this breadth of research areas, as well as the growing diversity of university departments and schools that are part of the computing and IT field.

One area of particularly great and increasing national importance in both research and education is health IT. The challenges that this area addresses range from assuring that the federal government and the country's health care system meets the needs of modernizing and standardizing health records, to providing powerful and easy-to-use information technology systems that support health care providers, to creating tools and systems that allow individuals to monitor and improve their own health independently. It is clear there are tremendous needs and opportunities in Health IT, and this area should be considered as a strategic focus for NITRD.

Addressing Our Workforce and Education Needs

While everyone is talking about jobs these days—where to find them, how to create them—the computing industry is clamoring for the talent it needs to fill thousands of vacancies. The U.S. Bureau of Labor Statistic projects that the computing sector will have 1.5 million job openings over the next 10 years, making this one of the fastest growing economic fields. There are many pathways into these jobs, but a deeper look at the fastest growing occupations within this field (such as computer software engineers or computer and network systems analysts) shows they either will require a computer science or related degree or greatly benefit from the knowledge and skills imparted by computer science courses. It is gratifying to see that the report ″Networking and Information Technology: Workforce Study″ presented to NITRD in May 2009 by SRI, corroborated these widely used workforce projections.

Further, CNN's *Money* and PayScale.com ranked the "Best Jobs in America," and the number one job is Software Architect. Other computer science career paths also were high on the list, including Database Administrator at number 7, Information Systems Security Engineer at 17, Software Engineer at 18, and at least 10 other computing careers ranking in the top 50. I commonly forward articles about the jobs that are most in demand to our school's career services office; computing and IT jobs are virtually always on these lists.

During the past several decades, computing and IT has grown to address these needs. We have moved from a field focused on the foundational systems that make computers run (e.g., operating systems, programming languages) and applications in scientific computing and business data processing, to also encompass a wide array of general purpose computer applications (e.g., databases, computer graphics, robotics, computer security, graphical user interfaces) and discipline-oriented applications (e.g., bioinformatics, health informatics). Higher education has adapted both by greatly broadening the scope of computer science at many universities to embrace this breadth and by adding new schools of computing, informatics and information that enlarge or complement them.

In general, the students that are being produced by university computing and IT programs are meeting the needs of the IT workforce well; there are just far too few of them. Despite the tremendous job opportunities that computer science knowledge offers:

- Participation in AP Computer Science has been flat for a decade; [1]
- Interest in majoring in computer science among incoming freshman is at an all-time low; [2] and
- here is little ethnic and gender diversity among those who take computer science courses. [3]

This relates to insufficient exposure to computer science in K–12. We regard this as a fundamental issue that federal, state and local governments need to address to achieve its workforce needs.

[1] Growth in AP Computer Science tests taken has remained flat for the past decade while AP tests in other STEM fields have grown rapidly; see *http://www.acm.org/public-policy/AP.jpg.*

[2] Source: UCLA Higher Education Research Institute Survey of Incoming Freshmen.

[3] According to the National Center for Women and Information Technology, computer science education has significant equity barriers. In 2008, only 17 percent of Advance Placement (AP) computer science test takers were women, and only 4 percent (784 students) were African American.

ACM has been on the forefront of efforts to strengthen K–12 computer science education for years. Last year it spearheaded the formation of the Computing in the Core coalition to raise the national profile of K–12 computer science education. The founding members of this coalition are major stakeholders in the field of computing ranging from industry—Microsoft, Google, and SAS—to non-profit organizations, including the Association for Computing Machinery, Computer Science Teachers Association, National Center for Women and Information Technology, Computing Research Association, and Anita Borg Institute. Recently, the Coalition has grown to include the College Board, the National Council of Teachers of Mathematics and the National Science Teachers Association. Computing in the Core is united in our commitment to improving computer science education, which we strongly believe is marginalized in K–12 classrooms nationwide today.The marginalization of K–12 computer science education is a result of numerous federal, state and local education policies that do not make room for K–12 computer science education, coupled with deep confusion about what computer science education is in elementary, middle and secondary schools. A recent study, *Running On Empty: The Failure to Teach K–12 Computer Science in the Digital Age*,[4] revealed K–12 computer science education is currently focused on basic skills, which teach students how to consume technology, versus acquiring deeper knowledge and skills which teach them to create new technologies. Further, only nine states "count" computer science courses toward a core academic graduation credit. Finally, few states have robust teacher certification programs for K–12 computer science teachers.

The systemic absence of rigorous and engaging computer science in K–12 education starts at the local level, but there is a set of recurring policy issues that the Federal Government and the NITRD program can take strides to address:

- There are few states that have standards for computer science education and there are virtually no assessments for computer science education.
- Professional development for computer science teachers is limited as resources are focused away from this area.
- Computer science courses typically do not count toward a student's core graduation credit requirements.

While decisions on these issues are often vested at the state and local level, NITRD and the NCO can address obstacles in federal STEM education and workforce-related programs computer science faces to help creating breathing room for state-led reforms of K–12 computer science education. We make the following specific recommendations for the committee to consider:

- **NITRD programs should report to the NCO what steps they are taking to address K-12 computer science education reform.**
- NITRD has a Program Component Area (PCA) that includes education activities and specifically mentions the 21st Century workforce and K–12 education as strategic priorities. However, there is little specific attention to these issues within the PCA or prioritization within the NITRD program in general. Most education funding within the NITRD program is from the National Science Foundation (NSF), while the Department of Education does not participate in the NITRD program at all. Of the NSF activities, there appears to be little to no involvement with some of the key programs within NSF's Education and Human Resources Directorate focused on strengthening K–12 science, technology, engineering and mathematics education, including the Math Science Partnership program. We encourage greater ties with these programs, particularly MSP.
- We note that the CE–21 program within the Computing and Information Science and Engineering Directorate at NSF is one program focused on addressing K–12 computer science education. It has invested in the development of a new *AP Computer Science: Principles*[5] course intended to be broadly engaging and appealing to students, as well as other initiatives focused on reviving K–12 computer science education. The effort also rightly focuses on inclusion—making sure that the AP test and the computer science discipline appeal to a population of students diverse in race, ethnicity, socioeconomic status and gender. We support this program and point to it as model for addressing some of the key challenges in K–12 computer science education.
- **Include the Department of Education in the NITRD program**

[4] This study can be found at *http://www.acm.org/runningonempty*.
[5] See *http://www.collegeboard.com/html/computerscience/index.html*.

- As previously mentioned, the Department of Education is not one of the agencies currently participating in the NITRD program. Considering the key linkage between education and workforce, it is difficult, if not impossible, to address the workforce needs and the K–12 education issues, without having the Department of Education at the table. We urge you to ask the agency to return to NITRD.
- **Include and clearly define computer science in federal education programs.**
- Computer science means the study of computers and algorithmic processes, including their principles, their hardware and software designs, their applications, and their impact on society. Computer science education includes the following elements: design (both software and hardware), creation of digital artifacts, abstraction, logic, algorithm development and implementation, programming paradigms and languages, theoretical foundations, networks, graphics, databases and information retrieval, information security and privacy, artificial intelligence, the relationship between computing and mathematics, the limits of computation, applications in information technology and information systems, and social impacts of computing. [6]
- As schools have increasingly stepped up the integration, use, and teaching of information technology as tools that support learning, distinctions between these areas that involve the use of computing and IT as learning tools, and genuine computer science education have blurred. Educators and policy makers consistently confuse the *use of technology* and *teaching of technology literacy* with teaching computer science as a core academic discipline within the STEM fields. PCAST recognized this issue in their 2010 report, *Prepare and Inspire: K–12 Education in Science, Technology, Engineering and Math (STEM) for America's Future*:
- "Computer-related courses should aim not just for technological literacy, which includes such utilitarian skills as keyboarding and the use of commercial software packages and the Internet, but for a deeper understanding of the essential concepts, methods and wide-ranging applications of computer science. Students should gain hands-on exposure to the process of algorithmic thinking and its realization in the form of a computer program, to the use of computational techniques for real-world problem solving, and to such pervasive computational themes as modeling and abstraction, modularity and reusability, computational efficiency, testing and debugging, and the management of complexity."
- Federal programs exacerbate this confusion with vague terminology, as well as simply including "STEM" as eligible subjects. This often does not translate into computer science programs being included in the scope of the programs when they are implemented at the state and local levels. Relying on "STEM" as the foundational definition can inadvertently set up barriers for computer science. For example, NSF's Math and Science Partnership program specifically states that it is open to all "STEM" proposals; however, a closer review shows that grants must focus on improving "math and science" scores. Any proposal focused on computer science must show gains in math and science, not actually on computer science.
- For these reasons, it is crucially important that federal STEM workforce and education programs explicitly state that they include computer science. This recommendation is consistent with a recent report on PCAST that said computer science must be part of STEM education programs. As a coordinating body, NITRD should work with participating agencies to explicit include computer science as an eligible discipline within STEM education programs.
- **Create state planning and implementation grants for computer science K–12 curriculum and build national networks of support for K–12 computer science education**
- States should be developing specific, thorough plans to improve computer science education. Few states are deliberately integrating computer science into their K–12 offerings at elementary schools or ensuring its place in the high school curriculum. A broader capacity initiative focused on improving cur-

[6] ACM and CSTA have a four-part, grade-appropriate framework describing the standards for computer science education in K–12; see *http//www.csta.acm.org/Curriculum/sub/ACMK12CSModel.html.*

riculum, outreach and evaluation would build support for the goals and efforts of state planning and implementation of grants.

- As we previously recommended, bringing the Department of Education back into the NITRD program could create additional resources for such plans, but other NITRD agencies (such as the Department of Defense, NSF and the Department of Energy, which all house formal and informal education programs) should work directly with States to ensure state workforce and education needs are met. Establishing these plans or pilots for reforms within the States is a step toward addressing the deeper policy issues in K–12 computer science education.

- **Create pre-service and professional development opportunities for K–12 computer science teachers**

- Very few schools of education are focused on preparing computer science teachers, and because of a focus on "core" courses, there is limited professional development funding for computer science teachers. Federal agencies have numerous professional development and pre-service programs; however, we have consistently found little support for K–12 computer science education teachers within them. As course offerings in computer science grow, particularly with the new Advanced Placement Computer Science Principles course being introduced into schools, a program that specifically addresses the shortage of certified computer science teachers at the K–12 level is imperative, as are investments in professional development for those already teaching. Again, NITRD can play a role in raising this issue within agencies that have STEM or general education professional development or pre-service teacher programs.

The Computer Science Education Act

Provisions of the No Child Left Behind Act (NCLB) have also contributed to computer science's marginalization. Because of NCLB's accountability provisions and its definition of "core" disciplines, states have put resources toward investments in curriculum, pedagogy and professional development related to "core" courses. Furthermore, high school graduation requirements are tied to core courses. There are countless stories of teachers being pulled out of computer science courses to support the mathematics proficiency goals of NCLB. While you and your colleagues consider the future of NITRD, the House Education and the Workforce Committee is considering reauthorization of the Elementary and Secondary Education Act. Computing in the Core is working to ensure that a revised education law accommodates computer science in its provisions related to STEM education and ensures that computer science educators have access to the professional development and supports their colleagues do. The Computer Science Education Act from the 111th Congress represents our priorities related to programs administered by the Department of Education.

Conclusion

The NITRD program plays a crucial role in the development and health of the country's networking and information technology capabilities, and we strongly support the program. To meet the large and growing needs of this industry, the nation will require a much larger and more diverse array of computer science and IT professionals than it currently is producing. We welcome and applaud the inclusion of workforce, education and diversity issues in the NITRD program. We particularly encourage the NITRD program to play an active role in strengthening K–12 computer science education, as this is the foundational issue that needs to be address to bolster the population of students focusing on computing and IT at the university level, and entering the IT workforce.

Thank you again for the opportunity to appear before the Subcommittee today and for your attention. The groups I represent today stand ready to work with the committee to address our recommendations as NITRD reauthorization moves forward in this Congress. I'll be pleased to address any questions you have.

Chairman BROOKS. Thank you, Dr. Schnabel, and thank you the other panel members for your testimony.

Reminding Members of the Committee that Committee rules limit questioning to five minutes.

The Chair at this point will open the round of questions, and the Chair recognizes himself for five minutes.

This question is with respect to each of the witnesses. Each of you discuss the importance of federal investments in networking and information technology research and development, I am sure you are all also aware of the budget and deficit decisions facing the United States Congress. In looking at the FY 12 budget and what is already a finite amount for federal investment and will likely be even smaller next year, how would you prioritize federal NITRD investments?

Whoever wishes to go first.

Dr. STRAWN. Chairman Brooks, I will speak from the NITRD Coordination Program, for example. We certainly will have discussions with our agencies asking them how they prioritize their individual activities and then we will seek to mold that into a unified whole, looking for gaps that might have occurred as people prioritize away important activities.

So our goal of coordination may help in that activity.

Chairman BROOKS. Will you please report your results to this committee, submit a written report?

Dr. STRAWN. Yes, sir.

Chairman BROOKS. Thank you.

Dr. LAZOWSKA. Mr. Chairman, I think that America needs to decide in which areas of R&D it absolutely must be the world leader, and it needs to make extra investments in those fields. And I think this is the number one field in which America has to be the world leader. It has to be the world leader because this enables advances in all other fields because it drives our economy forward, because it is the largest source of science and technology employment, because it is essential to our national security and because if you want advances in areas like energy and transportation and health, then you need advances in this field. This is really the cornerstone of our economic success, our national security, and our discovery in all other fields.

So I honestly think that the question you need to ask is how to make very difficult choices among fields of prioritization, and I want to emphasize that the NITRD crosscut budget dramatically overstates the amount of funding that the Federal Government is actually spending on NIT R&D because of the categorization issues I addressed before.

The one other thing I would like to add is it is often tempting to confuse industry R&D for research that looks out a long way, and in truth the Federal Government is by far the most significant investor in research that looks out more than one product cycle. I am from Seattle. Microsoft is one of the computing companies that has a significant investment in research that looks out more than one product cycle. That is called Microsoft Research. It is about 900 people around the world, most of them in the United States, and it represents about four percent of Microsoft's R&D budget. The rest is very talented engineers producing, in caricature, the next version of Office and Windows. All right. It is R&D, but it is not what is going to lead to the next generation of breakthroughs. That is our job.

Dr. SPROULL. Mr. Chairman, not surprisingly, my counsel would be to be sure that the long-term investment remains as healthy as it can. Indeed, perhaps the entire investments need to be modulated, but I think we have shown that it is the long—as Dr. Lazowska was saying, the long-term has huge payoff and may lead to a brighter economy for all of us in that long-term.

And the cliche, I am afraid, is apt, which is let us not let the urgent drive out the important.

Dr. SCHNABEL. Mr. Chairman, I will just add briefly. I think a strategy always has to be a combination of things that are focused and things that are general. We have heard about some focused priorities in areas as health, energy, and security, but as we travel around the world, and all of us do that, one still hears in the countries that we now see as our growing competitors a great envy for the culture of innovation in this Nation that none of them can replicate. And to be able to sustain that we also have to leave room for things that are not as focused but will lead to that next round of innovation or otherwise we will be killing the goose that lays the golden egg.

Chairman BROOKS. Well, if I could just add a comment, Chairman's prerogative for a second, most everywhere I have been in Congress this year, everybody I talk to says their program is number one, and obviously, we can't fund everyone's program at number one given the financial circumstances we face unless we want to risk the Federal Government's solvency and bankruptcy, in which case every program would be last because we wouldn't have enough.

To give an example of the severity of the problem, last Thursday the Chairman of the House Armed Service Committee gave us a briefing on information he had received on the impact of some of these potential cuts on a national defense. We were looking at hundreds of thousands of military uniformed personnel, DOD civilian personnel, support contractors in the private sector that are going to be laid off or the positions will no longer exist. Talking about mothballing one carrier battle group, two nuclear submarines, 10 percent of our fighter aircraft and strategic bomber aircraft.

So if you can share with us any insight at some point in the future by submitting in writing to this committee a supplemental statement in which you share with us what you think your priorities for funding ought to be within NITRD, that would help us. If we have the amount of funding we have right now and we can fund everything at the same level, well, then that is fine. We don't have to get into that prioritization process.

But this is an opportunity for you to share with us your expertise about where the money ought to be spent if we are forced to deal with less overall. Otherwise, thank you for your comments.

Next I recognize Mr. Lipinski.

Mr. LIPINSKI. Thank you, Mr. Chairman.

This past Monday I was speaking to a group of constituents, and I was going through a job—five-point jobs plan I had put out a couple of months ago, and I said in there we need to invest in education, invest in innovation, and I think that is what you are talking about here.

And I think all of your testimony sort of really supports what I said why we have to do that is not only do we grow the jobs here in the United States, but you look at the 1990s, and we were able to grow out of the budget deficit to a budget surplus. You know, some of that came because we were able to grow, and you know, certainly was connected up with the really the explosion of the World Wide Web.

And so I think everything that all of you had said really supports that idea, and I think it is really critical as we do prioritize what really is—what really are good investments. I think the Chairman is correct. We really need to prioritize, but here I think that we are in the right place in terms of prioritizing this research.

I want—I was going to ask a question of workforce, but I think I am going to go instead because something Dr. Lazowska had said prompted me to go in a—to my second question first, and this is a question for everybody.

One of PCAST's recommendations, which Dr. Sproull in particular reiterated in his testimony, is for the NITRD Program to better account for the part of its budget that supports actual NIT R&D as opposed to NIT infrastructure that enables R&D and other science and engineering fields.

Should we be removing the budget for such infrastructure from the NITRD Program altogether? Are there downsides in narrowing the scope of the NITRD Program in this way? And finally, do we have a good estimate of what we are actually spending in NIT R&D if the NITRD budget is currently overcounting what we are spending?

Who wants to start on that? Dr. Lazowska.

Dr. LAZOWSKA. I will begin, and I am sure Dr. Strawn will have something to add. I want to say that I am speaking for myself and not for PCAST, and it is important to understand that.

My view and I think the view of our working group on the report at least was that it is entirely appropriate to continue to include those funds as part of the NITRD crosscut, simply to categorize them more carefully. There are already parts of the NITRD crosscut budget that account for infrastructure. For example, the acquisition of high-performance computing equipment.

But suppose that the National Institutes of Health, for example, spends substantial amounts of funding on databases for biomedical research. All right. Those are very, very important expenditures. They are crucial to driving biomedical research forward, they are IT, they belong in the NIH research budget, it is fine to have them as part of the NITRD Program, but they should be identified as the use of advanced information technology infrastructure to drive biomedical research forward.

As you perhaps know from reading the report, we asked an independent organization to look at several agencies, and the accuracy of the categorization varies widely across agencies, and I want to emphasize that no one is actively misreporting. What is needed is simply a more accurate characterization. Dr. Strawn and the National Coordinating Office have already taken steps in that direction, and I want to emphasize that this is a coordinating process that works.

And two quick examples. The previous PCAST report recommended increased emphasis on cyber physical systems, and a crosscutting program across multiple agencies was launched very quickly. The most recent PCAST report said increase the emphasis on large-scale data analysis, which is necessary for commerce, for scientific discovery, for national security, and we already have a big data senior steering group.

So it is really a very responsive coordinating process.

Mr. LIPINSKI. Who wants to go next? Dr. Strawn.

Dr. STRAWN. Yes, sir. Let me just say—thank you. The only thing I would refer back to is my use of the "Pasteur's Quadrant," book reference in my oral testimony about R&D being a two-dimensional structure, and it is—that sort of means it is not always clear what will produce the most important long-term research.

The project orientation, which has been effectively used by ARPA and DARPA and now by energy and by information and so forth where we have advanced research projects, may look like development or even look like infrastructure, but, in fact, if something entirely new comes out of it, it can spawn whole new research areas as well as whole new areas of activity.

As Dr. Lazowska mentioned, in one of our coordinating areas on high-performance computing, we have two sub-areas that we report separately, high-performance computing R&D and high-performance computing infrastructure and applications. This has been our largest area because there has been a large federal investment in high-performance computing, so we thought it was appropriate some time ago to break out those two distinctions. And it is certainly conceivable that we can break out in some of our other coordinating areas of similar situation, and I only caution that we shouldn't look for a sharp line between what is information science and supportive science and what is information science theory.

Dr. LAZOWSKA. Could I add a comment? Through the wonder of information technology, I was able to learn that the Navy's newest submarine is going to cost $13 billion, a $4 billion budget overrun. Just a news post on my iPhone. I want to emphasize that the National Science Foundation Computer Information Science and Engineering annual budget is in the order of half a billion dollars per year, and the corresponding DARPA Information Technology Investment is on the order of half a billion dollars per year.

These are very significant amounts of money, but they are rounding errors in terms of the federal budget, in terms of the cost overrun of a single submarine, and they are what power our Nation forward. Okay. It is those NSF and DARPA investments in information technology that make possible the prosperity we enjoy today.

So it is important to keep in perspective the relatively small amount of money that the Federal Government is investing in this field and the billion dollar industries, the many billion dollar industries that it creates.

Dr. STRAWN. We like to think our leverage factor or our multiplier factor is very great compared to many other federal investments.

Mr. LIPINSKI. It would be wonderful to see what you can—what can be shown as much as you can, that is not easy to do, but always getting back to, you know, what the Chairman emphasizes is, you know, prioritizing and anything that you can do to show the results is—would be very helpful.

So thank you. I yield back. Thank you for the extra time.

Chairman BROOKS. Thank you, Mr. Lipinski, and members of the panel, I would like to echo some of your comments. It would be wonderful if we would implement economic policies that will deal with some of the structural issues that have inhibited our country's economic growth. That is the best way to get out of this, and we all understand the pivotal role your sector has played in the economic growth that we have enjoyed in past years. Let's just pray that Congress and the White House collectively will do the right thing.

Next the Chair recognizes Mr. Bucshon of Indiana.

Mr. BUCSHON. I thank everyone for attending, and mine is going to be more focused on—less on budget and more on what type of research that we can be doing.

I am in health care. I was a heart surgeon before this. As you know there is a big push nationally, and this may not be as important as some of our national security issues, but it is important to our country, there is a big push, of course, for electronic medical records and patient—there is more and more patient data being stored permanently not on, for example, X-rays that are not on actual film but that are on hard drives around the country and around the world.

And from a medical standpoint right now, we have a system, as you probably know, which is a hodge podge of a multitude of different electronic systems, most of which are proprietary and don't communicate between each other, which just to give you an example in my hometown, Evansville, Indiana, we have two hospitals, and they both have different systems, completely different systems, no way to communicate. My medical practice had a system of electronic medical records with all kinds of data, no way to communicate with either hospital, and then a couple of the other practices now are putting in their own systems.

So I guess my question would be to the panel, you know, from a medical standpoint what type of, you know, what—is there anything going on out there to try to figure out how to coordinate this type of information, which is, you know, which is private medical information to make it more accessible to medical professionals, to make it more easy for the public to maybe even gain access to their own data? And because my view is if unless we can solve the security issues and the communication issues, actually electronic medical records are going to cost us money, not save us money. That is my view.

So I would be interested in anyone's comments.

Dr. STRAWN. Thank you for the question, Mr. Bucshon. In response to a Congressional legislation in the Auto Program, the NITRD Program stood up a senior steering group in health IT research and development. We have been working for approximately—more than a year now. We have attracted pure computing folks such as those at NSF and NIST, and we attracted many of the applied computing folks across HHS and DOD and other areas. We have a large senior steering group that has a—is looking at a large portfolio of possibilities and certainly electronic health records is one of those items.

We are moving toward focusing on, again, long-term issues, the creation of a health information infrastructure. Then the next step is how do we turn that information infrastructure into knowledge and action, how—while we are doing all this how do we empower the patient, the physician, everybody involved with access to that information turned into knowledge, and the devices, whether it is robotics or assistive devices in homes or electronic communication.

Those are at least four of the areas that we are looking at as we initially begin our dialogue with the health IT community, and my understanding is that there are more than 600 existing EHR systems, which just shows the size of the problem that you have alluded to.

One potentially small step in that direction is a high-level agreement that I understand has been reached between VA and DOD to interoperate their two electronic health systems. Our goal is to make that a prototype for something that will produce interoperability hopefully among all systems.

We certainly think that interoperability is more of a way to go than forcing one single standard. Just like the Internet itself was sort of a software network based that interconnected many networks that operated at a hardware level.

Mr. BUCSHON. Okay. Thank you.

Dr. LAZOWSKA. I was just going to add that this is clearly a place where the government can play a role, that is nudging industry to adopt standards and interoperability. There was a PCAST report in the past year on health IT that focused on precisely this issue; this is separate from the PCAST NITRD report.

You are absolutely right about the privacy and security issues, and that is something that really underpins all civilian, and of course, military use of information technology. It is an area where every federal agency needs more than we have today. We have not focused enough on long-range approaches to privacy and security. Our approach has been Band-aids rather than something that is going to get us out of this sort of rat race in which we are trying to keep ahead of the bad guys, and it is really going to impede adoption of this important technology.

The final thing I want to mention is that there are aspects of information technology and health that go beyond electronic medical records and will be in the future as important. The question I always ask is why my body is so less well instrumented than my automobile. You know, I bring the automobile into the dealership, and the mechanic sticks a jack in under the dash and reads out the last six months of data and tells me what the problem is, and when I go to see my physician, she hits me on the knee and says, "Where does it hurt?" to first approximation.

Okay. This has got to change, and there are many other areas where we will see change. For example, the genotype, phenotype correlation that is going to use big data to transform medicine in the future. So we need to invest in that entire spectrum.

Mr. BUCSHON. All right. Thank you. I think one more comment from a fellow Hoosier.

Dr. SCHNABEL. Yeah, and if I may, too, just briefly. First, to reinforce your point, in fact, the Executive Associate Dean of our medical school made the comment that he can go to India, put his bank card in an ATM machine, and it works, but if he walks across the street to a new medical provider, he can't get his records to follow him.

And we heard some comments about that, and it is a huge problem, but I do want to reinforce. I think it is really important for this subcommittee as we hear about health IT from each witness to realize the breadth of that field and that it includes clinical things which are much more than medical records themselves, also many things that assist physicians and doctors. It includes a whole consumer space of devices that we can use as individuals outside of medical care and even a population space of modeling of influenza and other things.

So it is a very rich space of research.

Mr. BUCSHON. Thank you very much. My time has expired.

Chairman BROOKS. Thank you. What we are going to try to do is get the next two Congressmen in. If we have time before votes are called, apparently there are some issues counting up the right totals, giving us a little bit more time; we might have a second round of questions.

But with that, Mr. Bartlett from Maryland, you are recognized.

Mr. BARTLETT. Thank you very much. We clearly are the most creative, innovative society in the world. We lead the world in computers and information technology. We can't even turn out people fast enough to fill the jobs available in these areas.

And in spite of that every 12 hours we have another billion dollar trade deficit. I am told that only three things ultimately produce wealth: mining, manufacturing, and farming.

Now, a lot of people have gotten very wealthy with computers and information technology, but, you know, you can't eat those electrons. They won't keep the rain off your head, they won't take you anywhere. Ultimately, at the end of the day, aren't these technologies simply enablers that help us to do other things better, that really create wealth? It isn't somebody else doing most of these other things better. To the extent that we continue to develop these technologies, aren't we just enabling our competitors?

What do we have to do so that we start doing the things that ultimately really create wealth, because are not these things simply tools that help us do these other things better and now somebody else in another part of the world is doing all these things better. What do we have to do so that we are encouraging the technologies that ultimately create wealth so that this billion dollars every 12 hours doesn't continue, because that is not sustainable?

Dr. STRAWN. Mr. Bartlett, I think you are certainly correct, and I think that is one of the reasons that one of the current focuses is on advanced manufacturing, which I interpret to mean the continual inclusion of additional IT services and capabilities into the manufacturing process. Farming, I might also say, I was last weekend at my brother-in-law's farm in Illinois where he is now farming by the foot with GPS technologies and so forth, so I think that we are beginning to use these advanced technologies in important ways and applications.

And my view is certainly these applications are the end result. It also turns out that the more theory we have the more applications we can serve. So both a balance between the theory and the application seems to me to be the most efficacious in terms of the long-term focus.

Dr. LAZOWSKA. I think our standard of living depends on our workers being more productive than workers anywhere else in the world, and information technology contributes enormously to that productivity in all sectors. Dr. Strawn addressed farming, and that is an important one. One hundred fifty years ago, if I recall correctly, something like 98 percent of employed Americans worked on the farm, and 100 years ago it was perhaps 50 percent, and now I believe it is 1–1/2 percent, and they produce enough food to feed our Nation and much of the world, and there are, of course, many contributors to that, including new crops and new fertilizers, but GPS and information technology plays an important role. That is why our service sector is more effective. Again, it is these productivity gains in the economy.

So our standard of living depends on us being more productive and more efficient, and that is what information technology brings to us.

Mr. BARTLETT. But we still have that billion dollars every 12 hours of trade deficit, and my question is being preeminent in these technologies, which I think are simply tools to help us do those things better that would free us from this dependence on foreign goods, how do we get from where we are with our clear superiority in computers and information technology area to where we are manufacturing, mining, the kinds of things that will free us from this intolerable trade deficit?

Dr. SPROULL. Sir, I would suspect that a lot of your billion dollars a day is energy costs, and all of the new energy sources, renewables and so forth, depend heavily on NIT for control, for production. As an enabler surely, yes, of the control system for both generating the power, distributing it, and improving the technologies as they go forward.

For example, one of the reasons high-performance computing was initially focused on—and the Act of 1991—was as a design aid to be able to model complex energy-producing technologies more accurately so that they would be more efficient. It has been used, for example, in things like how you burn coal more efficiently.

So that all goes to, it seems to me, helping reduce your deficit.

Mr. BARTLETT. Thank you very much, Mr. Chairman.

Chairman BROOKS. The Chair next recognizes Mr. Hultgren of Illinois.

Mr. HULTGREN. Thank you, Mr. Chairman. I apologize. It is kind of a crazy afternoon, so we are kind of coming in and out, have a couple different meetings at the same time but really do appreciate so much you being here. Chairman, thank you for hosting this meeting as well.

I do have a question. I had an interesting lunch today. We pulled a group of people together talking about the iPad, something that is very important in me getting through my day as far as keeping my calendar and information and things, but talking about the technology that led to the iPad and how so much of that was really started by basic scientific research and a commitment to physics and even the GPS. It was so interesting to hear how we got—and the requirement of the ultimate precision clocks that we have got that really allow for GPS to work as it does. It was amazing, so interesting.

But I just want to follow up, and I will start with Dr. Sproull if this is all right, in the testimony for today's hearing I know you all have talked about key technology advances, JAVA being one, iPad being one. Having been part of an industry applied research laboratory for over 20 years, what would you say are the three most critical and interesting changes or advances in the NIT industry since the early 1990s, and how did federal investment play a role in those advances that you would say?

Dr. SPROULL. Thank you. So the dominant one has to be the explosion of the World Wide Web, and the reason that exploded, the idea, as you know, came from a physics researcher in Europe, but the reason it exploded and the reason it exploded in the U.S. is the Internet was already there, and the basic communication protocols were in place, the switches were being built, things were starting to be deployed. It had migrated from a Defense Department prototype into the National Science Foundation where it was spread to wider academics, and then became available for commercial use at about the same time that the Web was invented, if you will.

And then—that is right, but what happened—but you asked what the development was. The explosion came because a usable browser was developed, and that was developed here as was discussed in your meeting this afternoon on your turf.

Mr. HULTGREN. Yes.

Dr. SPROULL. And moreover, the U.S. venture community figured out a way to form a company to capitalize on it, it became very valuable, at least on paper very quickly, because the market exploded. And that transforms so many other things. The other witnesses here today have pointed out how important infrastructure capabilities enable still other developments, not just new end products or new specific services but further developments. So we are doing things with the Internet today that Andreessen didn't dream of even in 1993.

So I have to say that that is one, two, and three, and the two and three if you really need two and three are things that came from one.

Mr. HULTGREN. Good. How about the rest of you? Are there—would you agree with that? Are there other things that you have seen very specifically that you would say, hey, this is—we need help in telling the story of how, what we are doing is vital, and our failure for basic scientific research for really what we talk about on this subcommittee and this committee in this Congress is it is not a zero sum game. If we don't do it, somebody else will, and I think Congressman Bartlett talked about that as well, and, you know, some of the care that we have to take in this.

But I would just be interested in hearing from the rest of you of what you have seen in your experience that maybe is most startling or most influential as far as advances.

Mr. STRAWN. Well, Dr. Sproull mentioned the Internet and things that derive from it. One of the things I believe that is deriving from it right now and is at early stages but may turn out to be of considerable importance is cloud computing. Cloud computing is in some sense a recentralization of computing where all of your software and your data are on centralized servers rather than on your own PC.

Now, obviously there are tremendous security and privacy issues associated with that, but some people have described this as the industrialization of computing, and it may turn out to be of extreme importance, and it derives directly from the availability of the Internet.

Dr. LAZOWSKA. Let me mention a few things that are entirely different today than they were 10 years ago, and I will mention a couple of civilian things and some military things.

One Dr. Strawn just touched on and that is the way we build these extremely large-scale systems. It is just totally different, totally different. What we do now is use unreliable hardware components because you can't possibly build systems as large as we need with reliable hardware. You couldn't afford to. You couldn't physically do it. So we use algorithms to make them reliable. That is a total change.

Second, search. Ten years ago you used to actually file stuff away. Now you just search for it, you know, and I can't remember the last time I put something in an electronic folder.

A third is mobility, the fact that you carry your whole life around with you, and again, all of these technologies trace themselves right back to the fundamental research program.

A fourth one is digital media. The fact that photographs and videos and audio, all of that material today is created and edited and consumed in a digital world rather than an analog world. You know, when was the last time you saw 35 millimeter film as an example, but, you know, I don't even have CDs and DVDs anymore. My music is on my Mac Mini, and my movies come over Netflix, over the Internet.

So these are things that have changed our lives and are totally different now than they were just 10 years ago, and you can trace every one of them back to the research program.

If you look at America's military situation today in logistics, our ability to deploy troops appropriately around the world, in robotics, the drone aircraft, for example, that are used around the globe, large and small, the small-scale robots for investigating areas, search and rescue, exploration where you can't send individuals. Even things like natural language translation, the military for a number of years now has used artificial intelligence systems to simply determine which five percent of the documents in foreign languages are worth having some human look at, which is a 20-to-one reduction in the number of translators you need.

So, you know, our military competitiveness today really depends on information technology in every imaginable way.

Dr. SCHNABEL. And if I may, I will just remind us that the visual that Dr. Sproull used, that tire tracks diagram is, indeed, an answer to this question, because it actually traces back nearly 20 industries in most cases to university NITRD-sponsored research groups.

Mr. HULTGREN. That is great. Well, again, thank you all. Appreciate the work that you have done. It is interesting, I think, even with my own kids, I kid them sometimes when they are playing with our family camera and just say, don't waste the film, because I remember my mom always saying that. Mom and dad, don't waste the film. Now you don't even think about that, but I also think back to my high-computing days in college of having a Commodore 64, and that was cutting edge. So it is amazing how far we have come.

So, anyhow, thank you all so much. Appreciate it and yield back, Chairman. Thank you.

Chairman BROOKS. Thank you, Mr. Hultgren.

The Chair recognizes Mr. Lipinski of Illinois for a brief period.

Mr. LIPINSKI. Thank you, Mr. Chairman. I just wanted to—I'm going to put this question for the record. I just want to throw it out there and sort of give you a heads up. I think the question of we come back to jobs, and we have the issue here—I think there are two things that make a career in NIT particularly difficult in the private sector.

First, the fields move so quickly that it takes constant education and training to stay in the game, and second, some of the jobs are very easily outsourced. You can move almost anywhere if you have a computer and you have the network connection.

So we don't have time to go into the—an answer, so I am just—but I think that is an issue. I am just—would like to have a—if we get a written response following up on, you know, what we can do to address this problem, what can we do to avoid training people for jobs that might not exist, is it something we can do, are there specific areas or programs that we should focus on, what is the best way for us to try to address this?

But like I said, I don't think we have time here. I will formally give that as a question for a written response. I want to thank all of you for your testimony here today, and this is something that I am hopeful that we can have legislation on in this Congress.

So thank you, Mr. Chairman, for the hearing.

Chairman BROOKS. I would like to thank the witness panel for the insight that you have shared with us. Quite frankly I think both Mr. Lipinski and I wish we had more time for follow-up, but as you have heard the bells and buzzers go off in this place, that means that we have got to get on the House Floor shortly to vote.

With that having been said, the Members of the Subcommittee may have additional questions for the witnesses, and we will ask you to respond to those in writing. The record will remain open for two weeks for additional comments from the Members. The witnesses are excused, and this hearing is adjourned.

[Whereupon, at 3:13 p.m., the Subcommittee was adjourned.]

Appendix

Answers to Post-Hearing Questions

ANSWERS TO POST-HEARING QUESTIONS

Responses by Dr. George Strawn, Director, National Coordination Office,Networking and Information Technology Research and Development (NITRD) Program

Questions submitted by Chairman Mo Brooks

Q1. As discussed at the hearing, Congress recognizes the value and importance of networking and information technology (NIT) research and development (R&D) funding; however, our existing budget constraints make prioritizing a requirement. Please detail how you would prioritize federal NIT R&D funding, what the top priorities would be, and how savings can be achived within the NITRD portfolio.

A1. As noted in my written testimony, all of the research reported in the NITRD portfolio is managed, selected, and funded by one or more of the 18 NITRD member agencies under their own individual authorizations and appropriations. Each NITRD agency engages in ongoing internal strategic planning and research prioritization activities to focus funding resources on those efforts most essential to carrying out its federal mission. NITRD agencies' published strategic plans typically identify their priority objectives in NIT R&D—the technical advances they need to meet mission needs.[1] These research objectives are refined and adjusted in the annual discussions within the Executive Branch and then with the Congress.

Since the NITRD Program serves as a coordinating organization, it does not manage the portfolio of federal NIT investments; each agency manages its own NIT R&D investments. However, the NITRD Program's research framework represents the agencies' shared mission R&D priorities, as well as broad federal priorities and basic research to support the longer-term goals of the Federal Government and to develop technologies that promote U.S. economic, scientific, and technological leadership. By collaborating on NIT R&D where it makes sense— such as in sharing high-end computing resources and codes for weather prediction—the agencies reap economies of scale and effort. As reported to Congress annually in the NITRD Supplement to the President's Budget, the NITRD research budget crosscut reports the agencies' NIT R&D spending and priorities. These priorities often also respond to directives of Congress and recommendations of the President's Council of Advisors on Science and Technology (PCAST) on technologies and capabilities deemed critical to the national interests of the United States. Examples include high-efficiency, "smart" power distribution systems; technologies to improve the quality, efficiency, and effectiveness of the U.S. health care system; next-generation tools for maintaining and working with "big data"; radio spectrum efficiency and broadband access; fundamental advances in cyberphysical systems in such domains as industrial process control, transportation, and medical devices: and advances in cybersecurity with Domain Name System Security Extensions (DNSSEC) to secure key aspects of the Internet's infrastructure.

In their NITRD Program activities, agencies identify shared high-priority technical challenges and address them together to leverage each other's research efforts. For example: NITRD's networking agencies collaborate to maintain a unified high-speed network infrastructure for federally sponsored scientific research; and the high-end computing agencies cooperate in a single benchmarking activity to evaluate new supercomputer systems—a labor-intensive, time-consuming effort previously conducted by each agency. By joining together to tackle key R&D issues they face in common, the NITRD agencies are able to leverage resources, minimize duplication of effort, and partner in investments to pursue shared goals. I would also note here that the unique and single most significant result of NITRD coordination is broadly applicable technologies and capabilities—NITRD advances often yield new, open technologies that can be adopted across the commercial landscape. A current example is PerfSONAR, a suite of network-monitoring tools developed by the NITRD agencies that enables managers for the first time to analyze network performance across multiple links; the tools are now being adopted by international research networks and the private sector.

To summarize, I believe the NITRD portfolio appropriately reflects current Federal NIT R&D priorities and budget constraints, and will continue to reflect that balance in the future.

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[1] For example: NSF 2011–2016 Strategic Plan, *http://www.nsf.gov/news/strategicplan/nsfstrategicplan_2011_2016.pdf*; DOE 2011 Strategic Plan, *http://science.energy.gov//media/bes/pdf/DOE_Strategic_Plan_2011.pdf*; DoD Information Enterprise Strategic Plan 2010–2012; *http://cio-nii.defense.gov/docs/DodIESP-r16.pdf.*

Q2. In your testimony you mentioned four specific component areas for the National Initiative for Cybersecruity Education (NICE): awareness, education, workforce structure, and workforce training and professional development. Are all NICE-funded activities captured under the agency budgets for NITRD? How much are we investing in NICE activities in total and in each component area?

A2. The NITRD Program is not tasked with tracking investments in NICE activities, either as a whole or by component area. NICE is an interagency effort led by NIST in which agencies identify common goals and milestones, commit their own resources toward achieving those goals, and align their respective implementation plans and activities. Implementation details for the goals and objectives outlined in the NICE strategic plan are currently under development and will be shared based on the policies of the agencies responsible for the execution of those details. NICE was formed under CNCI initiative 8, and budget figures are maintained by the Office of the Director of National Intelligence's Coordinate & Monitor team in the Office of National Intelligence Manager for Cyber.

Q3. A primary objective of the NITRD program is to support foundational computing research to drive innovation, productivity, and ultimately, economic growth. With that in mind, do (or should) agencies evaluate the degree to which a research proposal considered under NITRD may be connected to actual innovation and economic growth, as opposed to discovery science or climate science? Put another way, how does (or how should) the reality of limited federal support for computing R&D impact cross-discipline prioritization and project selection?

A3. The portfolio of research and development activities sponsored by the NITRD agencies constitutes this country's *primary* full-spectrum NIT R&D enterprise. I mean this in several senses:

- The member agencies of NITRD constitute the only U.S. research endeavor that funds investigations across the broad range of networking and information technologies. The Program's breadth is a vital characteristic because NIT technologies are uniquely interdependent and are developed from an inherently multidisciplinary basis in the sciences and in engineering. Collaboration among the NITRD agencies models the multidisciplinary nature of NIT challenges, and NITRD-funded projects often require multidisciplinary collaboration among performers.
- NITRD research is performed throughout the Nation—in universities, federal research centers and laboratories, federally funded R&D centers, private companies, and nonprofit organizations across the country. As noted in my testimony, the broad reach of NITRD activities generates continuous interaction, information exchange, and feedback, which provides new perspectives and insights to federal and private-sector stakeholders alike.
- Through its national scope, NITRD funding is the primary source of support for the education and training of the Nation's next generations of NIT researchers, technical experts, entrepreneurs, and NIT industry leaders.
- NITRD investments also span the NIT research spectrum, from fundamental inquiry to applied development. The balance varies from agency to agency, with NSF and DOE/SC emphasizing foundational research and agencies such as DARPA and DHS leaning more toward applied development. As noted in my testimony, research in networking and information technologies requires both theoretical investigations and "use-focused" applied engineering—and NIT innovations depend on the back-and-forth flow of ideas between the theoretical and the practical.
- Although not reported in the NITRD crosscut, NITRD agencies are increasingly focusing on the transition from laboratory to marketplace, using Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) grants to speed the transition to practice of NITRD-developed technologies. This important stage of advanced development also is explicitly addressed in "Trustworthy Cyberspace," the forthcoming strategic plan for R&D in cybersecurity developed by NITRD's Cyber Security and Information Assurance (CSIA) agencies. Transition to practice is also a focus of such new efforts as DHS cybersecurity R&D solicitations and NSF's Innovation Corps. [2]

In combination, these characteristics make the NITRD Program a key national resource for seeding U.S. innovation of all kinds. If NITRD did not exist, today we

[2] *http://www.nsf.gov/news/news_summ.jsp?cntn_id=121879.*

would be inventing it. Per my response to your first question, I believe that the NITRD enterprise reflects substantial prioritization of federal efforts.

Q4. Given that participation in AP Computer Science has been flat for a decade, as we heard during the hearing, please explain how a new AP Computer Science curriculum will be any different. How will it not only increase the number of college Computer Science majors, but also promote greater ethnic and gender diversity?

A4. The new AP course—Computer Science (CS) Principles—has been designed from the beginning to be engaging, challenging, inspiring, and relevant for all students. It is better than the existing CS AP course, which had been designed to mimic what colleges had been doing in their first course for CS majors. (Many colleges are rethinking their introductory sequences, especially their introductory courses for non-majors, and a number are looking at teaching CS principles.)

The number of academic computing courses taken by U.S. high school students is very low: The percentage of U.S. students taking science, technology, engineering, and mathematics (STEM) courses has increased over the last 20 years for all STEM disciplines except computer science, where participation dropped from 25% to 19%.[3] High school computer science teachers report teaching 8% fewer CS advanced placement (AP) courses in 2009 than just two years earlier.[4] In most high schools in the U.S., there is no academic computing course that carries college preparatory credit. (Often the only courses offered focus on keyboarding or application proficiency in Microsoft Word or PowerPoint, for example.) As a result, most U.S. students arrive at college with little or no understanding of what computing is as a scientific discipline; they know what chemistry is and what physics and math are, but they have no idea about computing.

The lack of high school experience in computing differentially affects women and minorities. Women have few female role models to counter the popular images of computing as a singularly male-oriented endeavor. Minorities are affected because they are more likely to be at low-resourced schools that provide fewer opportunities to study computer science.

How can we get more academic computing courses into our high schools? One key has to be Advanced Placement. AP classes—regardless of area—carry college preparatory credit in most schools. In addition, AP is rigorous, has fidelity of replication (all students must be readied for the same test), and is popular with students, their parents, school administrators, and college admissions offices. Thus, AP provides a single point of leverage to begin curricular change.

Why hasn't the current AP CS course succeeded in attracting students? The current course is a year of Java programming. Students, especially those with no prior experience with computers, see little reason to take it. It is a low-level, detailed introduction to programming. What students need, I believe, is a course that is engaging, rigorous, and inspiring. They should learn to program, but the course should not be programming-centric. Instead, it should cover the design of algorithms, the potentially transformative role of technology, the breadth of its applications, its role in enhancing creativity and augmenting human capabilities, the uses of big data, issues of complexity and computability, and societal impact and ethical considerations. In short, the course should be challenging but also exciting and relevant to students' lives, no matter whether they end up in a NIT career or not.

CS Principles has been designed to meet these criteria. Its initial reception has been positive. It was piloted last year at five universities and this year is being taught in roughly 20 universities/colleges (including some of the top CS departments in the country) and 40 high schools. More than 200 high schools vied to be part of the official College Board pilot, which was restricted to 10 schools.

In addition to CS Principles, a pre-AP course, called Exploring Computer Science (ECS), has been developed with NSF funding and uses a similar philosophy. Both CS Principles and ECS appear to be successful in attracting women and underrepresented minorities.[5] For example, in four years within the Los Angeles Unified School District, ECS enrollment has jumped 553% and now tops 2,000 students, 80% of whom are African American or Latino, and 40% are female. In the CS Principles course taught at the University of California at Berkeley in the fall of 2010, 60% of the best-performing students were female (including the top student); in a

[3] 2009 NAEP High School Transcript Study; *http://www.nationsreportcard.gov/hsts_2009*.

[4] 2009 Teacher Survey, Computer Science Teachers Association; *http://csta.acm.org/Research/sub/HighSchoolSurveys.html*.

[5] From reports of Principal Investigators to Program Officers of NSF's CE21 Program.

predecessor course the year before, women had been only 40% of the most successful students.

Q5. The U.S. Department of Education is not currently a member of NITRD. Why are they no longer participating in the program, and why should they be at the table?

A5. The Department of Education has not been a formal participant in the NITRD Program for well over a decade, although ED representatives now and again join in NITRD activities. The NITRD Program would welcome the Department's re-engagement, and we have sent a formal letter of invitation to the Department inviting their participation.

Questions submitted by Ranking Member Daniel Lipinski

Q1. As I mentioned during the hearing, the fast-moving nature of the fields and the ease with which some jobs can be outsourced can add uncertainty to careers in NIT, especially in the private sector.

- *Do you see the outsourcing of NIT jobs as a problem, and if not, why?*
- *Are there things we can do to avoid training people for jobs that might not exist?*
- *Are there specific areas or programs on which the federal agencies should focus?*

A1. These are difficult issues, about which there are undoubtedly widely divergent and strongly held viewpoints. I stated in my testimony that I believe our global leadership in NIT is under challenge from many competitors. The NITRD agencies are greatly concerned about the development of the U.S. workforce, given that we are moving at an ever-increasing pace into a pervasively digital future. Our agencies see the need to better prepare our population to live and work successfully in the digital world as a national imperative. The U.S. must maintain the skilled workforce needed to compete in the global economy. Moreover, some outsourcing may directly affect national security—for example, the maintenance of the NIT infrastructure of the U.S. industrial base.

Strengthening the foundations of learning in computer science—currently woefully inadequate—at every educational level should be a national priority. The best way to prepare for change is to provide a broad, fundamental education in this subject, beginning at the precollegiate level and continuing throughout college. If the education system provided that kind of foundational academic grounding, follow-on training and retraining activities would then become relatively easier, and Americans would be better prepared to adapt to shifting technologies.

Rather than trying to anticipate where employment opportunities will lie over the long term (Bureau of Labor Statistics studies [6] and others predict that skilled NIT-related jobs will be among the Nation's fastest-growing over the next five years), I believe we need to make a commitment as a society to integrate computer science into STEM education as vigorously as we set about improving math and science curricula after Sputnik. The generations of scientists and engineers we produced in that effort are the world's best. We should aim for nothing less in computer science and engineering. If we educate for NIT leadership, the challenges you cite will eventually recede in importance.

Q2. The percentage of women obtaining degrees in computer science is particularly low, and even more troubling, began to decrease around 2001 even as female participation in other STEM fields continues to slowly increase. The apparent rebound (as of 2009) in the number of women obtaining computer science Master's degrees appears to be entirely due to an increase in the number of temporary residents obtaining such degrees; the number of U.S. citizens and permanent residents continues to decrease. Do we understand why American women are turning away from computer sciences in such high numbers? Are there any data since 2009 to indicate that this trend may be changing? What additional steps could we take to increase the recruitment and retention of women in computer sciences? How can federal agencies such as the National Science Foundation and other NITRD agencies help with these efforts?

A2. There is no one reason for the low enrollments of women in computing. The lack of engaging, inspiring, and relevant computing courses in high schools, as discussed above, is certainly one of them, but popular culture perpetuates many false, negative images of computing as well. Women say, for example, that they are not

[6] *http://www.bls.gov/emp/ep_table_103.htm.*

as interested in computing because it lacks societal impact.[7] Computer scientists are often portrayed as quirky loners who work 24–7 with little human interaction. In addition, the male-dominated environment often found in computing labs may make women feel unwelcome or dismissed. Women (and minorities) see very few role models in the world of NIT.

The data do not show a substantive change since 2009.[8]

How do we fix this? There is no one answer. High school, as discussed above, is certainly key, but more is needed. As a society, we need to change the popular media's image of computing, and encourage high school teachers and guidance counselors to avoid perpetuating old stereotypes. Likewise, new best practices for increasing diversity in computing at the high school and college levels need to be developed and assessed, and guidance counselors and computer science educators need to make more of an effort to deploy solid recruitment and retention practices—for example, by improving outreach and communication with the female parents of female students to make them feel welcome at the CS table. The CS education community also needs to ensure that the learning environment in our computer science classes and departments is more welcoming of the contributions of minorities. Female CS undergraduates need to be provided with research experiences, internships, and mentoring, and women in NIT-related jobs from all age groups and professional levels need to be brought together for networking and mentoring.

How could federal agencies such as NSF help? The Computer and Information Science and Engineering (CISE) Directorate at NSF has long been committed to reducing the underrepresentation of women in computing. Currently, that effort falls under its Computing Education for the 21st Century (CE21) Program. CE21 recognizes that efforts to reform computing education and efforts to broaden participation must go hand-in-hand: It will not be sufficient to "fix" computing education if we continue to leave out close to 70% of the population (women, minorities, and persons with disabilities), and it will not be sufficient to engage women and minorities if we do not also build their competencies and skills. Both efforts must inform each other. Currently, CISE funds a number of projects aimed at increasing the participation of women. Two examples include:

- NCWIT (National Center for Women and Technology), which functions as a clearing house, resource center, and convener of people and events for the whole community, including in particular its Academic Alliance (more than 100 university departments), K–12 Alliance, Social Science Network, and Industry Alliance.
- CRA-W/CDC (Computing Research Association's Committee on the Status of Women in Computing Research (CRA-W) and the Coalition to Diversify Computing (CDC)), which focuses on research experiences and mentoring for undergraduates, and recruitment and retention for graduate school and successful early research careers.

Other NSF efforts include the support of the Grace Hopper Celebration of Women in Computing national and regional conferences (which bring students and professional women together for technical talks and mentoring), the support of the Dot Diva website created by WGBH for girls aged 13–17, and work with the National Girls Collaborative Project on dissemination of informal education activities for girls.

Q3. Does the National Coordination Office intend to implement the PCAST recommendation that a distinct presidential advisory council on networking and information technology (NIT), which existed as PITAC until 2005, be reconstituted as a standing committee? If not, why not? How do you respond to the specific justifications for this recommendation that are described in the PCAST report—namely that federal NIT investments require continuous attention by a focused committee of experts who can provide predictive rather than reactive advice?

A3. This recommendation is under discussion within the Executive Branch and among the NITRD agencies.

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[7] Recent national data on the status of women in computing are available from the National Center for Women & Information Technology, *http://ncwit.org* (e.g., *http://ncwit.org/resources.scorecard.html*).

[8] 2009–2010 Taulbee Survey, Computing Research Association; *http://www.cra.org/resources/crn-archive-view-detail/undergraduate_cs_degree_production_rises_doctoral_production_steady/*.

Q4. In your testimony, you mentioned the National Initiative for Cybersecurity Education (NICE), which is coordinated by NIST, but you did not discuss how NICE is coordinated with the education and workforce development program component area under NITRD. Can you elaborate on how these programs fit together, and in addition how the NITRD education programs are coordinated with the broader effort to coordinate federal STEM programs? What is the rationale for having parallel coordinating structures for NIT education broadly, and cybersecurity education specifically? Are there any disadvantages to folding NICE activities, including coordination activities, into the NITRD program and coordination activities?

A4. The NITRD Program's Social, Economic, and Workforce Implications of IT and IT Workforce Development (SEW) Program Component Area supports research on the co-evolution of IT and social and economic systems; innovative applications of IT in education; and the implications of IT for education and training overall. In recognition of the importance of the education and training component, the SEW agencies formed a SEW-Education Team to consider ways to help foster improved education and training in computer science. These NITRD activities are closely coordinated with the NICE program at NIST through the appointment of the NICE Lead as the co-chair of the SEW-Education Team in NITRD. This is enabling SEW-Education members to shape broader but complementary activities to help address the systemic education problems discussed above. The Team is monitoring the start-up activities of the National Science and Technology Council's new Committee on Science, Technology, Engineering, and Math Education (CoSTEM), called for by the America COMPETES Reauthorization Act of 2010, and anticipates working to align its activities with the directions identified in the CoSTEM five-year strategic plan now under development.

Thank you again for affording me the opportunity to address the important questions you raise on a topic so vital to the future of our country. On behalf of the NITRD Program, I look forward to working with you to sustain our Nation's leadership in networking and information technologies in the years to come.

Responses by Dr. Edward Lazowska, Director, eScience Institute, Bill and Melinda Gates Chair, University of Washington

Questions submitted by Chairman Mo Brooks

Q1. As discussed at the hearing, Congress recognizes the value and importance of networking and information technology (NIT) research and development (R&D) funding; however, our existing budget constraints make prioritizing a requirement. Please detail how you would prioritize NIT R&D funding, what the top priorities would be, and how savings can be achieved within the NITRD portfolio.

A1. As you know, I co-chaired the Working Group of the President's Council of Advisors on Science and Technology for the recent PCAST review of the NITRD program. One of the key recommendations in that report was a call to establish "a broad, high-level standing committee of academic scientists, engineers, and industry leaders dedicated to providing sustained strategic advice in NIT." We view the establishment of such a group (really, the re-establishment of such a group—it would be analogous to the President's Information Technology Advisory Committee which existed under the Clinton and Bush administrations) as essential. Such a group would be perfectly positioned to answer the question you have posed, and many other important questions.

With that said, the PCAST report did attempt to address this question. The report includes recommendations for research areas of particular importance to national priorities—health information technology, energy and transportation, and the security and robustness of cyber-infrastructure—as well as a call for increased investment in a number of fundamental NIT research areas that will accelerate progress across a broader range of priorities, including: privacy and security; human-computer interaction; data analytics, including data collection, storage, management, and automated large-scale analysis based on machine learning and predictive modeling; and computing in the physical world, through advanced sensor and control networks, innovative robotics and other means. I personally agree with these recommendations and would offer them to the committee.

It is, however, difficult to discuss the size of the investments required, if only because it is very difficult to get an accurate understanding of the size of the current investment. As I reported at the hearing, and as PCAST mentioned in its report, agency reporting of NIT R&D investments is, in places, very questionable. While investments reported by the National Science Foundation and DARPA are reasonably accurate portrayals of NIT R&D spending by those agencies, it appears that much of the spending reported by other agencies is more accurately characterized as "NIT investments in support of other areas of research" rather than "NIT research funding." In fact, PCAST found that between 89 and 98 percent of the reported investment in NIT R&D by the National Institutes of Health was not NIT R&D, but rather the use of IT in support of other areas of research—for example, public databases of research-related information. While this is valuable and appropriate research spending, it's not NIT R&D, and calling it NIT R&D leads to the belief that we are spending far more on NIT R&D than we really are.

This leads to another key point that I raised in response to a question during the hearing. You of course appreciate the role of NIT R&D in driving our economic competitiveness, in achieving our major national and global priorities, in accelerating the pace of discovery in all other fields, and in achieving the goals of open government. Quoting PCAST, "As a field of inquiry, NIT has a rich intellectual agenda—as rich as that of any other field of science or engineering. In addition, NIT is arguably unique among all fields of science and engineering in the breadth of its impact." Despite this, the federal investment in NIT R&D is exceedingly modest by any measure. It is important for the nation to identify those fields of science and engineering in which we must lead the world. It is impossible to imagine that any field would have higher priority than NIT. Compare the federal NIT R&D investment, though, to that of other fields!

A final point: While high performance computing remains a critical area of focus for the NITRD program: (1) other areas of NIT—for example, robotics, and large-scale data analysis—have risen to equal levels of importance as measures of our international competitiveness; (2) this is true even for applications in national security and scientific discovery, traditionally the bastion of HPC, where large-scale data analysis (which requires significantly different architectures and algorithms) is of great and growing importance; and (3) even within numerical computing, we need to rely on a better metric than "FLoating-point Operations Per Second" (FLOPs)—the default measure of supercomputing "power" on lists of the world's most powerful supercomputers—to assess our progress and leadership in the space; landing at the top of the Top 500 List is exceptionally expensive and does not necessarily guarantee the nation will build a machine that's particularly useful; far more valuable a priority is to invest in research that could allow for a leap frog of current high performance computing technology.

Q2. In your testimony, you quoted from the PCAST report, restating that, "All indicators —all historical data, and all projections—argue that NIT is the dominant factor in America's science and technology (S&T) employment, and that the supply of that talent is and will remain large." When did NIT become the dominant factor in S&T employment? Are other S&T sectors dwindling, or is this due to the growth in the NIT field?

A2. The data on the growth of the IT workforce need comes from projections developed by the U.S. Department of Labor's Bureau of Labor Statistics. These are 10-year projections released every two years. For at least a decade, these projections have shown that employment growth in the "computer science and mathematics" sector will far outstrip growth in all other science and technology fields combined (and this growth is almost entirely in the computer science fields). In fact, the individual formerly in charge of these forecasts for BLS famously once said "All other fields of science and engineering are hiding behind information technology" by which he meant that the vast majority of the overall STEM (Science, Technology, Engineering, and Mathematics) workforce gap and job growth was in the computing fields.

My read of the statistics is that this represents the pervasiveness of NIT throughout the U.S. economy. The growth in employment is not just due to the growth of the IT sector, though that's certainly an element, but in the use of NIT across industries, from health care to banking to transportation to energy and beyond, as a means of improving productivity and gaining other efficiencies. So it's not that these other fields have become less important, it's that NIT and NIT workers have become increasingly important to these other fields.

Q3. Your testimony stated that "The workforce needs of the IT fields going forward demand a sustained effort to increase the number of students going into computing fields." Why aren't students entering the computing fields today? What can academic institutions and industry do to encourage student involvement and engagement?

A3. The good news is that, after a period of declining enrollments that began at around the time of the "Dot-com bust," data from the Computing Research Association's Taulbee Survey tracking enrollments and graduation rates indicates that the trend has reversed and that student interest in computing majors has increased in each of the last two years. Anecdotal evidence from my own department and from colleagues around the country suggests that this year's survey results will likely show much larger increases in enrollments. At the stronger programs across the nation, enrollment is booming.

Enrollments in computer science are somewhat cyclical and do correlate to some degree with the overall state of the IT economy. In the "Dot-com boom" times, computer science enrollments increased faster than many university programs could handle. The bust that followed decreased enrollment, but it appears the highly visible success of many NIT-related companies like Facebook, Google, and Apple may be motivating large numbers of new students to pursue computing-related careers, resulting in the positive numbers we see now.

While enrollments are important, it's also important that we retain an adequate number of those students interested in research careers through their Ph.D.s. In those cases, federal support for university research plays a crucial role in supporting the researchers who will employ those students as graduate researchers. These graduate researchers are like the lubrication in the innovation ecosystem, enabling the transfer of ideas gleaned from fundamental research into industry and the marketplace. Federal support for research not only enables that fundamental research, it helps train the students who will take that fruits of that research into industrial research labs with them or into their own startup companies, such as Google, which, only a dozen years after its emergence from Stanford, has a market capitalization of $190,000,000,000, employs 32,000 people, and is a verb.

Questions submitted by Ranking Member Daniel Lipinski

Q1. As I mentioned during the hearing, the fast moving nature of the fields and the ease with which some jobs can be outsourced can add uncertainty to careers in NIT, especially in the private sector.

- *Do you see the outsourcing of NIT jobs as a problem, and if not, why?*
- *Are there things we can do to avoid training people for jobs that might not exist?*
- *Are there specific areas or programs on which federal agencies should focus?*

A1. Let me say at the outset that the Bureau of Labor Statistics workforce projections cited in my testimony and in response to a previous question—which indicate that domestic workforce demand in the computing sector during this decade will far outstrip demand in all other fields of science, technology, engineering, and mathematics combined—account (as best BLS can) for offshoring. Computing is a field of enormous opportunity for well-prepared people in our country, and will continue to be so.

The issues of outsourcing within the IT sector are complex, and determining the impact is made difficult by the uneven quantity, quality and objectivity of the data available. But the computing community has tried to understand some of the issues involved. In a report entitled "Globalization and Offshoring of Software," a task force of the Association for Computing Machinery concluded the following about potential increases in "offshoring" of NIT work:

- Globalization of the software industry is likely to continue to grow.
- Both anecdotal evidence and economic theory indicate that offshoring between developed and developing countries can, as a whole, benefit both.
- Because of the lack of good data, skepticism is warranted regarding claims about the number of jobs to be offshored and the projected growth of software industries in developing nations.
- Standardized jobs are more easily moved from developed to developing countries than higher-skill jobs, but competition in higher-end skill jobs is increasing.
- To stay competitive in a global IT environment and industry, countries must adopt policies that foster innovation. Policies that improve a country's ability to attract, educate, and retain the best IT talent are critical. Educational policy and investment is at the core.

The bottom line is that information technology remains a sector in which the nation must retain leadership in order to be globally competitive—competitive economically and technologically superior for our national defense. The ease with which some aspects of NIT can be outsourced only heightens the need to ensure that the ecosystem for research in the U.S. remains strong. As a nation, we can afford to offshore technical support. We cannot, however, afford to offshore innovation. There must be a far greater emphasis on Bachelors, Masters, and Doctoral education at strong institutions which prepare students to be innovators.

Q2. The percentage of women obtaining degrees in computer science is particularly low, and even more troubling, began to decrease around 2001 even as female participation in other STEM fields continues to slowly increase. The apparent rebound (as of 2009) in the number of women obtaining computer science Master's degrees appears to be entirely due to an increase in the number of temporary residents obtaining such degrees; the number of U.S. citizens and permanent residents continues to decrease. Do we understand why American women are turning away from computer sciences in such high numbers? Are there any data since 2009 to indicate that this trend may be changing? What additional steps could we take to increase the recruitment and retention of women in computer sciences? How can federal agencies such as the National Science Foundation and other NITRD agencies help with these efforts?

A2. This is an issue of enormous concern. It is not just a matter of "equity" or of "workforce"—it is an issue of "quality," since computer systems intended for use by the full breadth of our population must be designed by individuals who reflect the full breadth of our population.

This is also an area of intense focus, over many years. This is, in fact, bad news: The decrease in female computer science enrollment began in the 1980s, not in 2001, and we have been working to reverse the trend for many years. The discouraging numbers that you see today are despite decades of serious effort at assessing and addressing the problem.

The good news is that recent trends are positive. For example, between 2009 and 2010, the percentage of computer science Bachelor's degrees from research universities received by women increased, and the number of U.S. citizens and permanent residents enrolled in mathematics and computer science grew faster than the number of temporary residents.

I personally feel that the greatest problem is persistent stereotypes (think "Dilbert" or "geek"). The bad news about stereotypes is that they have at least a grain of truth in them, and thus they die hard.

What can federal agencies do? Support a greater number of graduate fellowships for women, because role models (as faculty members and researchers) are important. Support the Computing Research Association Committee on the Status of Women in Computing Research (CRA-W), which runs a number of highly effective programs. Support the National Center for Women in Information Technology (NCWIT), which also runs a number of highly effective programs. Support CRA-W and NCWIT so that they can focus on their work, rather than on their survival. Finally, support current efforts by the National Science Foundation's CISE Directorate to revamp the Advanced Placement curriculum in computer science, and to train 10,000 teachers in the next few years to teach this new curriculum—the CS 10K effort. All of these efforts are starving.

Q3. In your opening statement, you said that 60 percent of the new jobs created in this country over the next decade will be related to NIT. Could you explain the research or studies behind this figure? Will traditional courses of study (e.g., computer science) effectively prepare students for these sorts of careers? Are new pedagogical approaches needed? Do we need to revisit how we teach other areas, like engineering?

A3. The Department of Labor's Bureau of Labor Statistics every two years assembles workforce projections for a broad range of fields over the next decade. Over the last several cycles—going back more than a decade—BLS projections have consistently shown that projected increases in the computing fields completely outstrip all other fields of science, technology, engineering, and mathematics (STEM) combined. From what I can see, this is due primarily to two factors: the growth of the IT sector—that is, the producers of NIT hardware, software and services—and the increased use of IT across all other sectors. In fact, it is the latter factor which undoubtedly accounts for the largest share of the overall increase. NIT is being used to enable all other sectors to work more productively—to produce more while using fewer resources. Each of these sectors will require skilled workers to incorporate these new technologies effectively, creating literally millions of new opportunities for NIT professionals.

"Computational thinking" is transforming all other disciplines, and they are somewhat slow to respond. We need to integrate "computational thinking" into K–12 STEM curricula, and we need to integrate computation and computational thinking into other fields of science and engineering. Graduate programs in ″eScience″ (data-intensive science) are emerging today, and are an important trend that should be supported. eScience is the future of all science.

Responses by Dr. Robert Sproull, Director of Oracle Labs, retired

Questions submitted by Chairman Mo Brooks

Q1. As discussed at the hearing, Congress recognizes the value and importance of networking and information technology (NIT) research and development (R&D) funding; however, our existing budget constraints make prioritizing a requirement. Please detail how you would prioritize federal NIT R&D funding, what the top priorities would be, and how savings can be achived within the NITRD portfolio.

A1. I recommend that long-term research investments be protected, that is, that they not be reduced more than other spending. True, long-term NITRD research is risky, but it has consistently produced results with huge economic benefits to the nation, including growingjobs and federal tax revenues.

Q2. As part of the PCAST working group assessing the NITRD program, you said the group "had trouble determining the levels of research investment in different areas beecause of difficulties in labeling and measuring expenditures." You went on to say that industry makes "clear distinctions between different kinds of investment in IT, in part so that the investments can be balanced appropriately." Why can't the federal government do the same?

A2. As I detailed in my written testimony, private sector accounting distinguishes several categories for IT expenditures: expense of running IT services (including cost of depreciation of computers and other capital equipment); expense of development of IT services (e.g., software engineers developing "routine IT"); and expense of NIT research to explore new and risky innovations in NIT products and services. These categories clearly distinguish operating, development, and research expenses.

It would be helpful to distinguish these categories in federal spending as well. However, federal accounting is different—there is no equivalent of depreciation, for example. It would be helpful, however, for the NITRD agencies to report their investments in categories similar to these, as recommended in the PCAST NITRD report.

Questions submitted by Ranking Member Daniel Lipinski

Q1. As I mentioned during the hearing, the fast moving nature of the fields and the ease with which some jobs can be outsourced can add uncertainty to careers in NIT, especially in the private sector.

Q1a. Do you see the outsourcing of NIT jobs as a problem, and if not, why?

A1a. I distinguish between "outsourcing," in which a firm contracts with another firm to perform work, generally resulting in fewer jobs in the first firm and more in the second; and "offshoring," in which a firm in one country (the U.S.) pays for work performed in another country, whether using its own employees or those of a contractor. The principal concern is with offshoring, which shifts jobs out of the United States.

In my experience working with highly trained and innovative researchers, we seek people with the best and most appropriate talent, regardless of their nationality or location. We prefer to attract researchers to move to a domestically-located laboratory, but if they cannot we will hire them to work in their preferred location. A clear step to insure domestic hiring is to have strong graduate education in the United States and provision for its graduates, of whatever nationality, to be able to work in the U.S. Easing immigration of excellent researchers trained abroad so they can work in our domestic labs is also important.

This same approach of hiring the best wherever they are has caused foreign firms to open NIT research labs in the United States, where they employ U.S. citizens.

In NIT research, "offshoring" finds the strongest talent. If our nation can educate and retain the best NIT talent, domestic and foreign companies both will employ it in the U.S.

Q1b. Are there things we can do to avoid training people for jobs that might not exist?

A1b. Because of the time lag between a student's selection of study areas or majors and their entry into the workforce, typically after college, there is an unavoidable possibility of cyclic workforce surpluses and deficits. Students are quite shrewd in judging future demand; it seems to me that it would be hard to devise a better scheme.

Short-term training is less problematic: the job market changes slowly enough that a shrewd student will not embark on fruitless training.

Q1c. Are there specific areas or programs on which the federal agencies should focus?

A1c. To ensure the best NIT talent is developed in the United States rather than offshore, we must build strong STEM education programs in K–12 as well as in colleges. While a STEM background is not absolutely essential for NIT careers (philosophers who love logic can become exceptional software engineers!), STEM education must be strong if the NIT workforce is to be strong.

Q2. The percentage of women obtaining degrees in computer science is particularly low, and even more troubling, began to decrease around 2001 even as female participation in other STEM fields continues to slowly increase. The apparent rebound (as of 2009) in the number of women obtaining computer science Master's degrees appears to be entirely due to an increase in the number of temporary residents obtaining such degrees; the number of U.S. citizens and permanent residents continues to decrease. Do we understand why American women are turning away from computer sciences in such high numbers? Are there any data since 2009 to indicate that this trend may be changing? What additional steps could we take to increase the recruitment and retention of women in computer sciences? How can federal agencies such as the National Science Foundation and other NITRD agencies help with these efforts?

A2. I do not feel qualified to answer this question. I defer to my academic colleagues.

Responses by Dr. Robert Schnabel, Dean, School of Informatics, Indiana University

Questions submitted by Chairman Mo Brooks

Q1. As discussed at the hearing, Congress recognizes the value and importance of networking and information technology (NIT) research and development (R&D) funding; however, our existing budget constraints make prioritizing a requirement. Please detail how you would prioritize federal NIT R&D funding, what the top priorities would be, and how savings can be achived within the NITRD portfolio.

A1. I agree that the NITRD program should prioritize funding for research and development. As I mentioned in my testimony, health IT is an area of particularly great national importance. The challenges that this area addresses range from assuring that the Federal Government and the nation's health care system meets the needs of modernizing and standardizing health records, to providing powerful and easy-to-use information technology systems that support health care providers, to creating tools and systems that allow individuals to monitor and improve their own health independently. I also agree with the recent PCAST report that recommended prioritizing funding toward IT applications in security, energy and transportation.

As Dr. Lazowska noted in his testimony, it is difficult to assess the overall size of research funding focused on computing since it is co-mingled with funding for IT infrastructure; therefore, it is difficult to assess potential savings. Getting a better handle on what NITRD funding actually is going toward research versus funding for information technology infrastructure that supports research in other areas would help better assess where savings could be achieved. The highest priority of the NITRD portfolio should be funding focused on high-risk, possibly high-reward IT research.

I also support the recommendation of the recent PCAST report for a standing committee of networking and IT specialists to oversee the federal IT research portfolio. This committee could continually review the program and help drive the establishment of priorities for funding.

Q2. You indicate that the Federal Government needs to include and clearly define computer science in federal education programs and create pre-service and professional develpment opportunities for K–12 computer sceince teachers. Computer science is included in many federal education programs. Are there any you know of that specifically prohibit computer science as an eligible field? If so, please describe.

A2. I am not aware of any programs intended to address K–12 educational needs that explicitly prohibit (by law or regulation) computer science as an eligible discipline; however, there are many instances where the additional restrictions of the programs implicitly rule out or discourage computer science or put computer science programs at a severe competitive disadvantage. Education programs—such as the "STEM" education programs within the Committee's jurisdiction—often erect barriers that either bias against or exclude computer science because of where computer science currently exists within the U.S. K–12 system. For example, as described further below, many federal programs expect proposals to build up either a strong assessment base in the discipline and/or certification of teachers, or are linked to "core academic subjects." Computer science teachers face much different issues in the K–12 environment than teachers of mathematics, and existing programs often do not take this into account. These conditions create a chicken-and-egg problem that makes it difficult for computer science to be included.

Because of the accountability provisions in No Child Left Behind and the focus of States on that Act's "core" disciplines in developing high school graduation requirements, investments in curriculum, pedagogy and professional development very often are focused on "core" courses. There also has been a pronounced shift towards presuming that States will adopt the work of the "Common Core Standards Initiative" and its "college and career ready standards" in both the competitive grant guidance for the Race to the Top program and in the President's proposed Fiscal Year 2011 budget. In practice, this means schools, States and federal programs emphasize mathematics, reading, and natural sciences. Therefore, well-meaning federal legislation intended to improve STEM education broadly often does not include computer science at the state and local levels, since it is not typically considered part of this "core."

This same issue plays out in programs authorized by the COMPETEs Act and the Elementary and Secondary Education Act, putting K–12 computer science education in a classic "Catch–22." Because computer science is not part of the core, it does not have the same level of assessments or teacher support as core programs that education policy makers seek to improve course offerings, but it is difficult to develop these without being in the core.

An important example is the NSF's Math and Science Partnership program. This program has five types of awards, including Targeted Partnerships intended for "a specific disciplinary focus in mathematics or the sciences." At a high level, the program is broadly STEM focused seemingly to be a "big tent" for all STEM-related disciplines. In fact, the COMPETEs Act amended what was then current law to clarify the scope of the program to include all of the STEM disciplines. However, guidance to grant applicants asks specifically for baseline data on how the proposals will improve student achievement in mathematics and/or science standards. However, the significant public investments in mathematics and science assessments rarely address computer science. Therefore, computer science proposals have difficulty meeting the baseline data requirements. This puts computer science proposals at a distinct disadvantage relative to mathematics and science proposals, which deters would-be applicants and creates a barrier for the computer science field.

This same type of Catch–22 pertains to multiple COMPETEs Act programs that would require "highly qualified" computer science teachers. For example, the MSP award category Teacher Institutes for the 21st Century was created by the COMPETEs Act. The scope of the program is to serve STEM teachers who "are considered highly qualified." The COMPETEs Act references the underlying definition of "highly qualified" in the Elementary and Secondary Education Act (ESEA). One of the requirements for teachers to be highly qualified is certification and demonstrated knowledge in the subject area in which they teach. (Other programs in COMPETEs that rely on the highly qualified criteria include Teachers for a Competitive Tomorrow and the Robert Noyce Teacher Scholarship Program.) Very few States have certification programs for computer science teachers. Thus, although these programs do not explicitly prohibit computer science, their requirements often have the effect of making computer science ineligible. These same issues appear as barriers for schools distributing Title II funding under the Elementary and Secondary Education Act.

In summary, the "STEM" designation in numerous federal programs often does not recognize and account for the reality that the computer science discipline faces in the schools. Many federal STEM programs are designed for the core academic structure in schools across the country. At the state and local level computer science courses can be classified as mathematics or science courses, but in 35 states it is simply an elective. Effectively this means that computer science teachers and courses are treated differently than mathematics and science teachers and courses. Clearly including computer science in STEM education programs, and clearly defining that this means the conceptual aspects of computing (as opposed to basic technology literacy) as the President's Council of Advisors on Science and Technology recommended, would help address the lack of applicability of federal STEM programs to computer science in numerous states across the nation.

Q3. Given that participation in AP Computer Science has been flat for a decade, as we heard during the hearing, please explain how a new AP Computer Science curriculum will be any different. How will it not only increase the number of college Computer Science majors, but also promote greater ethnic and gender diversity?

A3. The new computer science AP course, *Computer Science Principles*, follows the model of several other redesigns of AP courses by focusing on the fundamental aspects of the field in a way that is engaging, relevant to the real world and inspiring for all students. It seeks to show how important computer science is to many areas of our society while giving a broad introduction to the subject area. Thus, this largely a "breadth" approach. The increased appeal of the course is tied to this approach.

In contrast, the current AP Computer Science A course is largely a "depth" approach that goes deeply into the specifics of the Java computer programming language and gives little sense of the broad applicability of computer science. Students without prior programming knowledge often find the course difficult or unapproachable, and the course makes no attempt to appeal to students who are attracted more by the broad societal applicability of computer science than by the technical material for its own sake. The demographics of the current AP CS A course are very clear; the AP test data shows that largely white males take it and in small numbers relative to other AP "STEM" disciplines. Teachers often have pointed out that the current course is not an ideal first course for students new to computer science, and because computer science courses have little room in the curriculum, the current AP computer science course may be the only opportunity students have to get exposure to this field in secondary K–12 education.

Computer Science Principles contains rigorous content and includes a programming component, but uses programming as a way of exploring the broader concepts of computer science. Unlike AP CS A, it is more about learning core computer science concepts and much less about learning the nuances and syntactical specifics of a particular language.

One reason to expect that this new approach to AP computer science will attract more students and a more diverse set of student is the positive results of other "breadth" approaches towards teaching computer science. For example, a new high school level course, Exploring Computer Science, has also adopted this foundational, problem solving approach to introducing computer science to great success. The availability of this NSF-funded course in urban, public schools has led to rapid and dramatic results. Over the past four years, over 4,000 Los Angeles public high school students across 25 high schools have taken this college preparatory course—of which 40 percent of enrolled students were girls and 80 percent were students of color. This type of foundational and contextual approach to computing around which the new AP Computer Science Principles course also is framed holds great promise in drawing students into computer science, particularly students who have been historically underrepresented in computer science.

Q4. Many of your recommendations fall outside of the jurisdiction of this Committee and, in some cases, the scope of the Federal Government. However, I am curious. I understand how you could teach middle and high school computer science skills like programming, software development, and the use of algorithms; but exactly how would you teach a first or second grader computer science beyond basic skills?

A4. Like all academic disciplines, computer science involves the development of knowledge and skills that are best introduced and mastered incrementally as students move through their education experience. For this reason, the Computer Science Teachers Association has developed the K–12 Computer Science Standards which provided learning outcomes keyed to students' intellectual development at several milestones throughout their schooling experience. These outcomes are organized into two levels at elementary school, grades K–3 and 3–6. Elementary school students are introduced to foundational concepts in computer science by integrating basic skills in technology with simple ideas about computational thinking. For example in grades K–3, a student begins to develop an understanding of sorting by beginning to arrange information into a useful order. In grades 3–6 students can begin to develop a simple understanding of an algorithm that includes sequencing of steps and sorting of information. In Grades 3–6 students can also begin learning the foundations of algorithmic problem solving starting with breaking down a larger problem into smaller steps that are easily solved.

To illustrate an even more specific answer to the question, CSTA's new draft standards for K–12 computer science reference the resources at Computer Science Unplugged (*http://csunplugged.org/*), which include some specific approaches to meeting the learning objectives of sorting or how computers represent numbers as 1s and 0s in grades K–2.

Questions submitted by Ranking Member Daniel Lipinski

Q1. As I mentioned during the hearing, the fast moving nature of the fields and the ease with which some jobs can be outsourced can add uncertainty to careers in NIT, especially in the private sector.

Q1a. Do you see the outsourcing of NIT jobs as a problem, and if not, why?

A1a. In short, no, this does not appear to be a major problem. We increasingly operate in a global economy and major firms increasingly employ a global workforce. As long as trade barriers generally are low, markets and talent exist in other countries, and our nation's standard of living and wage scales are higher than those in the developing world, it will be attractive for firms to locate some jobs overseas, particularly lower-level jobs. But if in conjunction, the employment situation in NIT continues to thrive in the United States, which it does, this is a ramification of a global economy but not a sign of trouble for the U.S. IT industry.

Every indication, both from government studies and data from corporations and universities, is that the employment situation in NIT fields in the U.S. shows a considerably greater demand for workers than the current supply, and this it will continue this way into the foreseeable future. The latest Bureau of Labor Statistics projections for 2008–2018 predict a 22.3% growth in employment in the computing sector (the "computer specialists" category 15–1000 in the report) with 1,384,600 job openings over this 10-year period out of a projected 4,187,000 total jobs, meaning that 33% of the jobs will need to be filled with new workers. Those of us who work in computing fields in academia see this phenomenon up close, as the corporate demand for our students always exceeds the graduates we can supply. In the last two years, this situation has heated up even further. There also is verification of this same excess of NIT jobs vs. supply of workers from the corporate sector; for example, in July 2011, Microsoft general counsel Brad Smith reported in testimony before the Senate Judiciary Subcommittee on Immigration, Refugees and Border Security that as of May 2011, Microsoft had over 2,600 vacant computer science positions. In addition, the recent Dice report "America's Tech Talent Crunch" identified shortages of information technology talent in virtually all of the key IT markets in the nation including Silicon Valley, Seattle, Dallas, Boston, Atlanta, New York, and the DC/Virginia/Baltimore region.

Finally, it should be emphasized that in general, it is the lower-level, more commodity computing jobs that go overseas. Of the 10 BLS subcategories under computer specialists, the only one that shows a small projected decrease (2.9%) is "computer programmers," but this is far more than offset by a projected 30.4% increase in "computer software engineers, systems software," a category that is also considerably more highly paid. In many ways, a computer software engineer is an upgraded version of a computer programmer. This illustrates the general point: as long as we train U.S. citizens for the higher-level computing jobs, the ones that not only require technical skills but also applications knowledge and the ability to work with clients and customers, there will be plentiful job demand for them.

Q1b. Are there things we can do to avoid training people for jobs that might not exist?

A1b. There definitely are steps that we should take, and that many U.S. universities are taking, to make sure that the education and training that students receive prepare them well for the needs of the U.S. workforce. The main one is consistent with the points mentioned above: we need to prepare people for the modern, quickly-evolving world of computing technology where computing is applied in a huge variety of business, scientific, social and other contexts. Industry increasing looks for employees who combine technical expertise with the ability to interface with applications that range from health care to media, and who have the ability to work on diverse teams and with clients. U.S. programs in computer science, information technology, informatics and related fields increasingly are taking this orientation and preparing students well, although the number of students specializing in these fields remains insufficient.

The other crucial consideration is to realize that the computing world evolves so quickly that no training can prepare people sufficiently for a 10-year career, to say nothing of a 40-year career; students and workers need to be prepared to constantly learn new areas and skills. An education that goes beyond the purely technical to combine the applications knowledge and communication skills mentioned above also prepares the student well for lifelong learning. Universities will continue to need to evolve their curricula to meet the demands of a fast-moving industry, and corporations will need to compliment this education with more specialized training that keeps employees current and teaches skills that are particular to that company.

Q1c. Are there specific areas or programs on which the federal agencies should focus?

A1c. The federal agencies will be best served by supporting computing education broadly within the U.S. at the K–12 and higher education levels. The agencies should encourage educational approaches that increase the quantity and diversity of students who are attracted to NIT fields. These approaches include imparting not only the technical content of computing but also a sense of the wide range of applications and situations where computing leads to a better world. Applications in fields including health care, media and communications, energy, transportation, arts and entertainment should be made apparent to the students.

Q2. The percentage of women obtaining degrees in computer science is particularly low, and even more troubling, began to decrease around 2001 even as female participation in other STEM fields continues to slowly increase. The apparent rebound (as of 2009) in the number of women obtaining computer science Master's degrees appears to be entirely due to an increase in the number of temporary residents obtaining such degrees; the number of U.S. citizens and permanent residents continues to decrease. Do we understand why American women are turning away from computer sciences in such high numbers? Are there any data since 2009 to indicate that this trend may be changing? What additional steps could we take to increase the recruitment and retention of women in com-

puter sciences? How can federal agencies such as the National Science Foundation and other NITRD agencies help with these efforts?

A2. There is no easy answer as to why girls and women are opting out of computing; that is an important reason why, in 2004, the Computer and Information Science and Engineering directorate of the National Science Foundation provided funding to start NCWIT, the National Center for Women & Information Technology, whose mission is to significantly increase girls' and women's meaningful participation in computing. Since then, over 300 organizations (universities, corporations and non-profits) have worked together to understand the underlying causes and possible solutions of the low participation of women in computing. Causes include:

- The lack of rigorous, relevant and inclusive computer science instruction in K–12 education; curriculum needs to be formulated in a manner that attracts all students and not just predominantly males, by combining exposure to the applications and societal implications of computing with purely technical content.
- The lack of relevant and inclusive computer science introductory instruction at the post-secondary level.
- The pervasive image of computing as a "white geeky male" endeavor, and a lack of understanding that most computing professionals apply computing to a variety of fields ranging from health care to media to entertainment.
- The lack of exposure for computing educators to research concerning unintended bias and stereotype threat.
- The lack of understanding about computer science, and hence encouragement to pursue computer science education, by adult stakeholders.

While women's overall participation in university computer science education has not yet turned the corner, members of NCWIT's Academic Alliance reported recently that the percentage of female enrollments in their majors has increased, according to a 2010 annual survey conducted by NCWIT's external evaluator. Sixty percent of the survey respondents reported increased enrollment of women and 39% reported increased graduation rates. It is expected that growth in graduation rates will continue, since students take four to five years after enrolling to graduate. National data are beginning to corroborate members' reports. Although women's share of all computer and information science Bachelor's degrees awarded in the U.S. declined slightly between 2007 and 2010, two NCWIT-only datasets as well as the Computing Research Association dataset (one-third of which are NCWIT members) show an increase in women's share of degrees awarded. Furthermore, as the NCWIT academic alliance membership grows, so does NCWIT's influence on the overall percentage of computing degrees awarded in the U.S. In 2010, NCWIT academic alliance member organizations awarded 21% of the nearly 41,000 Bachelor's degrees awarded in computer and information sciences, an increase of 8% from 2007, when NCWIT members graduated 13% of all CIS degrees.

Increasing women's participation in information technology education and workforce requires a systemic approach that gives attention to multiple factors: recruitment of women by making them aware of the opportunities, particularly for helping society, that a computer career provides; development of computing curricula that combine technical skills, applications, and communication and teamwork skills; support for women students that recognizes that women often enter computing programs less confident of their abilities than men; and support for women in the technical workplace that provides the flexibility to balance careers and lives. Ultimately this requires high-level commitment by universities and employers to the importance of this issue to our society's economic competitiveness. Organizations taking this systemic approach do show results; as just one example, my own School of Informatics and Computing at Indiana University Bloomington has succeeded in doubling the number of women undergraduate majors, from 75 to 150, in less than two years by taking such a comprehensive approach.

Three key things that federal agencies can do to help with these efforts are to include programs that support diversification of the NIT student body and workforce in their funding portfolios, to support organizations that are producing successes in these areas, and to promote the importance of a diverse NIT workforce for our nation's economic health and competitiveness.

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